Olive Production in the Coastal Environment of Metalliferous Hill Country

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The olive crops produced in each area are the result of interaction between the environment and species requirements, the balance in which is maintained through agricultural practices.

In herbaceous plants correlations have been found between temperature/rainfall pattern at specific phenological stages and crop size (4,32). The same method has been applied to tree crops (35), including the olive (5,31,33), but the climatic series have often been linked to growth, phenological stages or crops without access to enough data to ensure proper statistical processing.

However, the models obtained for herbaceous plants which have an annual or biennial life cycle cannot be immediately applied to tree species which start to fruit as a result of changes in equilibria which guarantee their survival. Moreover, in the case of tree crops, interpretation of the interactive relationships between weather occurrences and phenological stages that are chronologically distant from fruiting depends on hypotheses of growth and/or nutritional and hormonal mechanism correlations that often have to be ascertained. In the specific case of the olive there are known to be interactions between crop left on the tree and the tendency towards alternate bearing (9,25), while in the case of the next year's harvest, models linking growth to bud induction are still only at the theoretical stage.

MATERIAL & METHOD

The crop data used for this research were recorded between 1968 and 1989 on the "Numerouno" estate in the Follonica district (Grosseto). The estate has 35 ha of olives, planted at an average density of 202 trees per hectare and located in a hill area where the soil is fairly uniform (red soils). It lies about 1 km from the sea. The orchards are about 40 years old on average and grow trees trained to a bushy vase shape, split between the following varieties: *Frantoio* (50%), *Moraiolo* (20%), *Leccino* (15%), others (15%). Ordinary cultural practices involve two spring-summer cultivations with toothed harrows and one fertiliser application with urea only (about 1 kg per tree each year). Harvesting is done by hand, with the aid of nets, and usually starts in early November and ends in the month of December. Pruning is carried out every two years.

The data processed were the actual crop figures registered at the estate mill where the olives were crushed. The temperature and rainfall data used were those recorded for the same years at the Hydrographic Office's weather station in Follonica (Pisa section), which lies about 1 km from the estate orchards. The data examined were minimum and maximum temperatures, mean temperatures and precipitation (mm).

TABLE 1
STATISTICAL DATA ON PRODUCTION (kg/tree) AND BIENNIAL BEARING INDICES

MEAN	11.4
STANDARD DEVIATION	3.4
MINIMUM	4.2
MAXIMUM	17.9
I index	0.206
B index %	78.95
RP index %	23.65

The study is divided into two parts. The first analyses crop characteristics and the major climatic variables. The second studies simple correlations in order to define critical periods for growth, during which one or more weather occurrences may modify crops. As suggested in literature (1,2), the annual vegetative-crop cycle has been split into 3 different stages comprising a total of 11 subperiods.

1) Four subperiods - a,b,c and d - have been identified in the vegetative growth stage (stage V - vegetative):

a) budding and first burst of growth: March-May;

b) maximum growth: June-July;

c) vegetative rest: August;

d) second burst of growth: September-October.

2) Six subperiods - e,f,g,h,i,l - were identified in the period during which the phenomena connected with the reproductive cycle occur. The entire period when the fruits are on the tree up to harvesting has been considered (stage R-reproductive):

e) induction and differentiation: December-March;

f) flower bud formation: April-May;

g) bloom: early to mid June;

h) fruit set: mid June-early July;

i) fruit growth: early July-late October;

l) presence of fruit on tree: June-November.

3) Lastly, lipogenesis, considered as the substantial accumulation of oil in the fruit and hypothetically defined as the period between August and October, was identified as stage “o”.

The weather data for each individual subperiod were correlated with the crops recorded for the year concerned and the one that followed.

In addition to this method, the authors tested the system proposed by Baltadori (5). Climatic data were drawn up by calculating the temperature mean and total rainfall for sets of 5 days (pentads). These were then re-assembled into groups of 4 to form 20-day periods on which the correlations were drawn. It was thus possible to test each two-year period, which represents a full vegetative-crop cycle, by adding a pentad each time and discarding the farthest one away in time.

Lastly, having identified the period definable as arid according to the method proposed by Bagnouls and Gaussen (1953), the effect was assessed of climatic variables during the arid period on the year's and following year's crop.

Correlations were calculated using the Statgraphics program. They also took into account the error introduced by the effect of the preceding year's production on the crop performance for the year being considered.

PRODUCTION

Over the years concerned (Table 1) average production was 11.4 kg/tree. This is a good figure for the area and above the provincial and regional averages (about 10 kg and 5.2 kg respectively). On comparison with the regional average, the characteristics of the province and area examined are suited to olive farming.

The pattern and size of crops are depicted graphically in Figure 1. Crops show some “irregularity”, although not to a marked extent, but it is not clear what rule lies behind this irregularity. Table 1 gives the “statistical values” for the crops in addition to the relevant indexes of alternation. These indexes (26), “I” to measure the intensity of the phenomenon, “B” to identify the percentage of bienniality (18) and “RP” to calculate the relative percentage between minimum and maximum production (26), are discussed at length in the paper by Monselise and Goldschmidt (25) to which we refer readers.

It would appear from the data that, given the agronomic conditions observed, alternate bearing as a phenomenon on adult trees is fairly controllable in this area. In fact, although the species is biennial with B values of close to 80, the range (I) of the swings is small in appropriate series of years. Comparison of the maximum and minimum production can be misleading if the crop trend over time is not considered. These crop values and alternation indexes are not dissimilar to those found in other types of trials on a different test plot not far away, although on a shorter time-series (38).

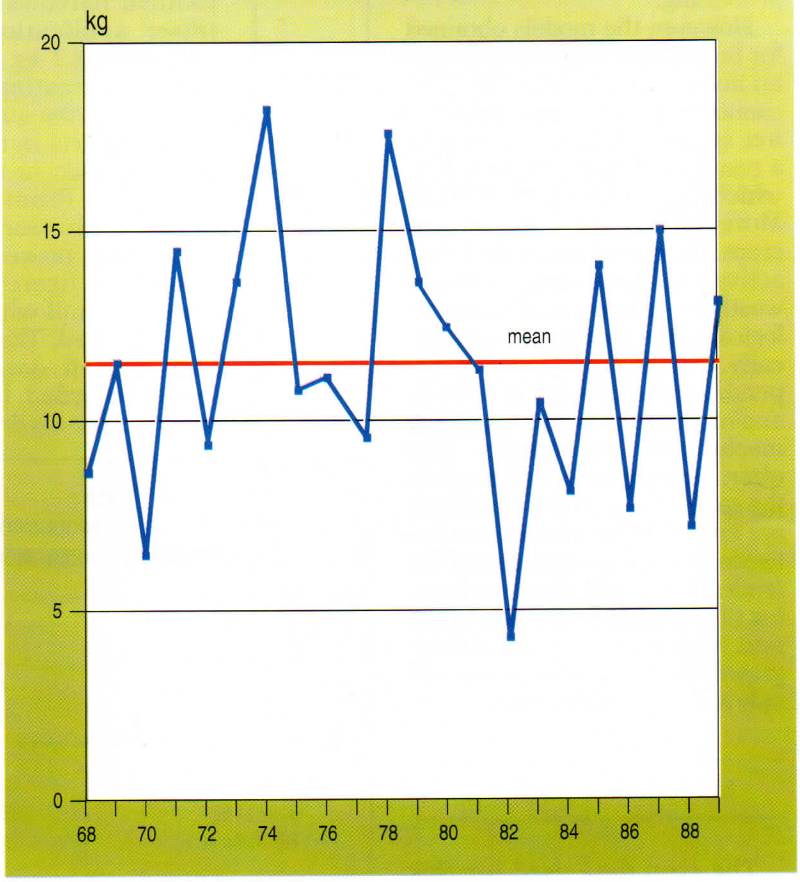
TABLE 2
MONTHLY AND ANNUAL RAINFALL IN MM
(mean period 1968-89)

MONTH	Monthly total	Minimum	Maximum
JANUARY	64.9	0.8	143.2
FEBRUARY	51.5	5.2	101
MARCH	54.4	9.6	140.4
APRIL	47.1	0.6	100.6
MAY	41.5	0	135
JUNE	23.2	3.8	83.2
JULY	15.5	0	87.8
AUGUST	53.6	0	190.6
SEPTEMBER	52.4	0	213.2
OCTOBER	73.7	15.6	168.4
NOVEMBER	76.9	2.2	176.2
DECEMBER	63.1	0	111.8
ANNUAL	617.8	418	942

CLIMATE

In the area examined, rainfall is rather limited, averaging out

FIGURE 1
Pattern of mean crops (kg olives/tree)



at 632 mm per year (Table 2); often in the spring-summer period little or no rainfall is recorded. On the other hand, rainfall becomes quite recurrent in late summer (August, September) which is characterised by stormy weather.

Minimum winter temperatures are moderate, rarely dropping to zero, while maximum temperatures in the summer (July and August) are attenuated by the proximity of the sea and are lower than those found inland in the same region. Theoretical freeze risk covers six months (from November to April) but at tolerable levels for the olive. Winter cold accompanied by heavy freezing can constitute a risk depending on the time of year. In January 1985 temperatures dropped to a low of -10 degrees C, and stayed below zero for several hours without causing severe damage to the trees as can also be seen from the production data.

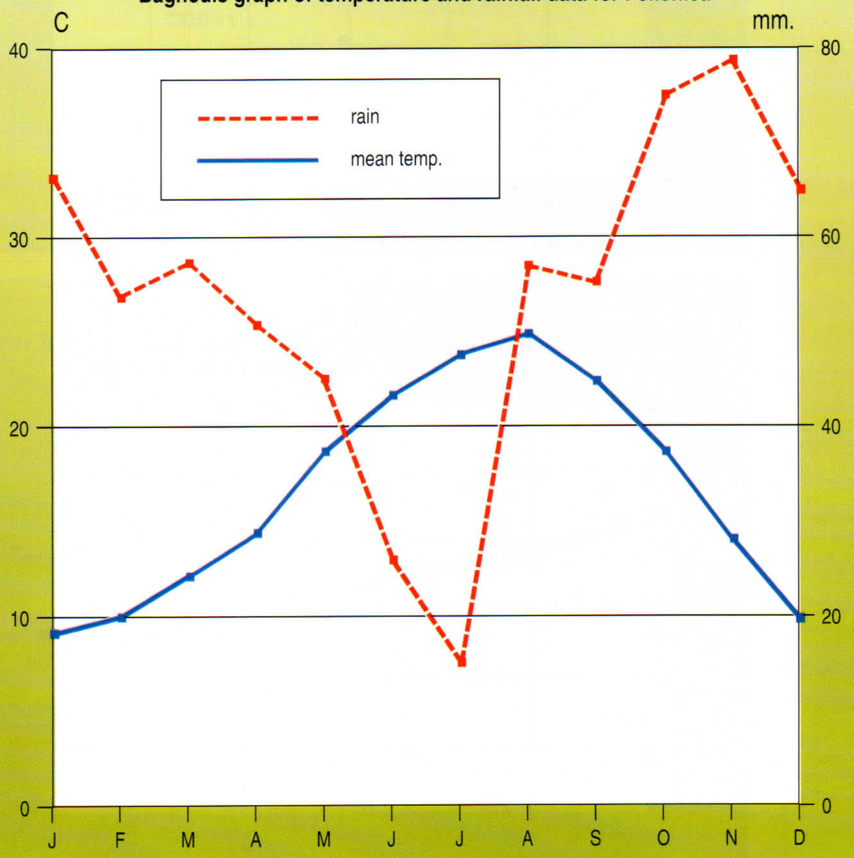
When plotted in graph form (Figure 2), the principal climatic variables (mean temperatures and mean monthly precipitation) show that there is definitely quite a pronounced "arid" period in the months of June and July.

According to Thornthwaite (9) this area can be described as semi-arid, without temperature extremes, a moderate winter excess of water and a dry period lasting 133 days.

***TABLE 3* : MEANS OF MONTHLY TEMPERATURE MINIMA AND MAXIMA (in degrees Centigrade) AND RELATED STATISTICAL PARAMETERS**
(mean for period 1968-89)

Month	Minimum	Standard deviation	Range	Maximum	Standard deviation	Range
JANUARY	3.8	2.4	8.3	13.1	2.0	7.8
FEBRUARY	4.5	2.2	7.8	14.0	1.6	5.8
MARCH	5.7	1.5	4.8	15.8	1.3	4.4
APRIL	7.9	1.0	3.8	17.8	2.0	9.5
MAY	11.6	0.9	3.4	22.4	1.6	7.1
JUNE	14.9	1.0	3.9	25.6	1.0	3.8
JULY	17.0	1.2	4.9	28.4	1.2	4.9
AUGUST	17.7	1.0	3.6	28.9	1.1	4.0
SEPTEMBER	14.9	1.0	4.3	26.2	1.4	4.9
OCTOBER	11.3	1.5	5.6	22.3	1.2	5.1
NOVEMBER	7.1	1.8	6.7	17.6	1.3	4.4
DECEMBER	4.3	1.6	6.0	14.1	1.3	4.4

FIGURE 2
Bagnouls graph of temperature and rainfall data for Follonica



RELATIONSHIPS BETWEEN CLIMATE AND PRODUCTION

The data in this paper show that the olive has a clear tendency to produce irregularly but no primary effect caused by specific rainfall combinations has been found.

When the I index is low, significant correlations do not readily emerge between crops and environment when observing a considerable number of years. The mechanism of biennial bearing may be triggered by exceptional climatic factors but in normal environmental conditions the response capacity of the species interacts with agricultural practices, resulting in a satisfactory degree of regularity in cropping.

EFFECT OF TEMPERATURES

It is believed that the olive needs winter chilling to produce a crop (13,14,15,16,17) and that in specific areas the colder the temperatures (obviously without causing damage) the larger the crop obtained (26,36,40). No correlation has been found, however, with mean temperatures, winter temperature minima or the month-by-month temperature assessments for November to February. This is probably because minimum temperature requirements are normally met in the area studied since even in 1985 when the lowest absolute minima for the period were recorded, a good, although not exceptional crop, was obtained (14.3 kg) which lies within the limits of the standard deviation. This crop followed on from three years of below-average production which no doubt contributed to predisposing the trees.

When the period of bloom is considered (late May-mid June) minimum temperature can be discerned to have a weak negative effect on the year's crop. In all probability temperature requirements are greater in this period, and these requirements are confirmed by the positive correlation with maximum temperatures for the same period (r=0.3256).

No correlation appears between winter temperature maxima and the major phenological stages. Only in mid-August is a significant positive correlation detectable (0.4828*) with the year's production although this cannot be readily explained as knowledge stands at present.

EFFECT OF RAINFALL

Analysis of the relationships between rainfall and productivity over a broad, consecutive number of years does not point to a direct relationship between mean yearly precipitation and production.

Particular attention was paid to the "arid" period. The rainfall recorded over June, July and August (Table 4) varied between 6.2 and 219 mm in the years covered, and the mean temperature was around 22 degrees C. In at least 15 of the 21 years, precipitation could be judged to be low. When calculated, no positive correlation is evident between the amount of rain fallen in this period and the crop obtained, and the coefficient of correlation is even negative (R=0.28).

It was also ascertained whether summer rains had an impact on the following year's

FIGURE 3
Relationship between production (kg olives/tree) and temperature minima mean during bloom

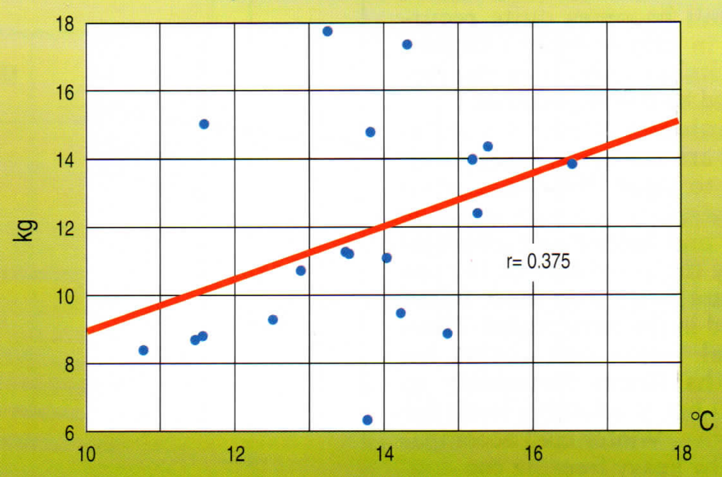


FIGURE 4
Relationship between production (kg olives/tree) and rainfall in preceding summer

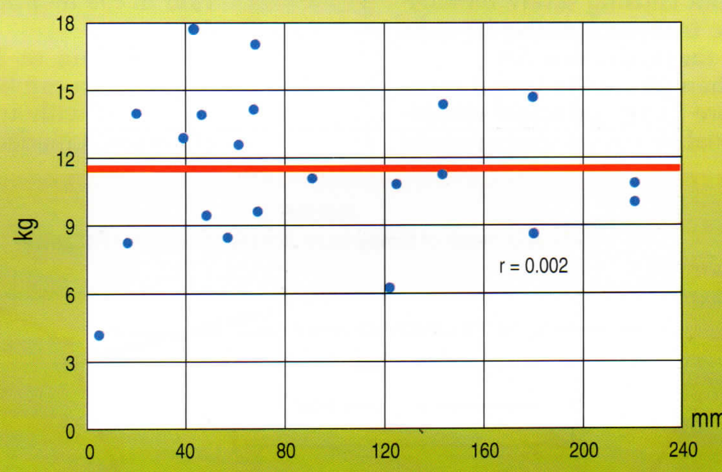


FIGURE 5
Relationship between production (kg olives/tree) and June rainfall

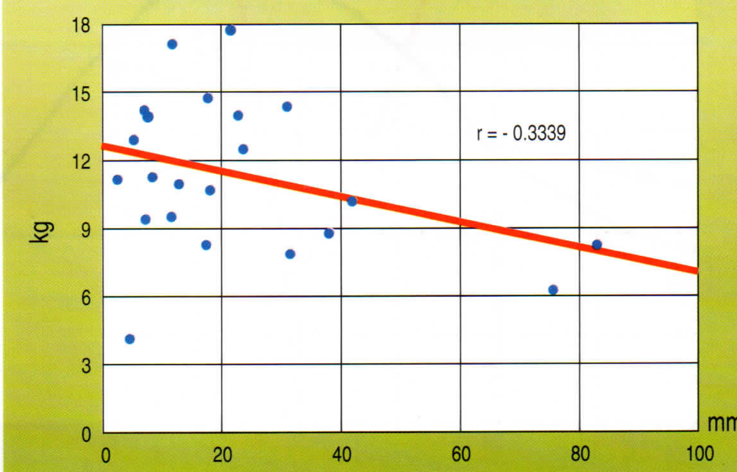


FIGURE 6
Relationship between production (kg olives/tree) and rainfall in preceding June

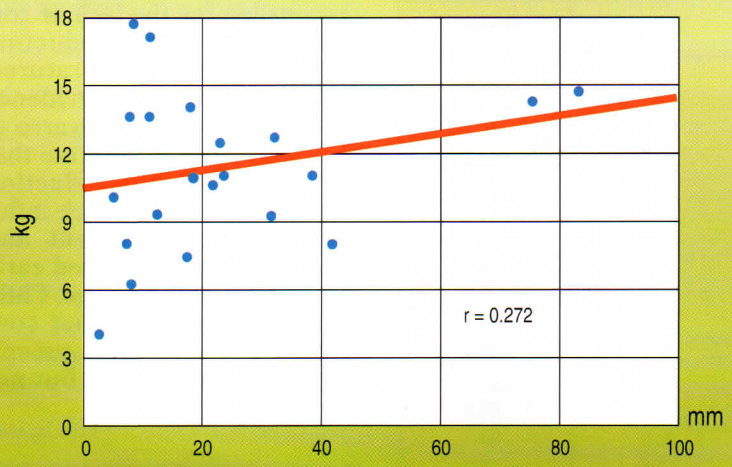


FIGURE 7
Relationship between production (kg olives/tree) and summer rainfall in "on years"

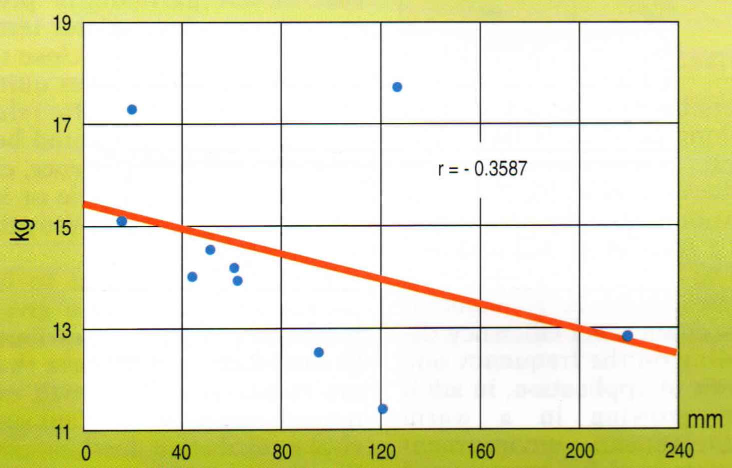
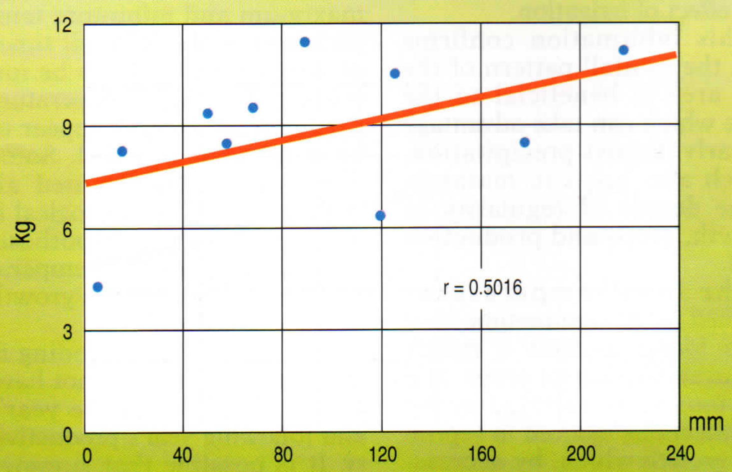


FIGURE 8
Relationship between production (kg olives/tree) and summer rainfall in "off years"



crop, working on the hypothesis that it might have a positive effect by improving the year's vegetative growth (24,37,39). However, here again, the coefficient of correlation did not reveal any relationship (r=0.002). Figure 4 reports the relevant straight-line regression where it can be seen that the values are distributed all along the plane with high production in years following on from scant summer rainfall.

Scrutiny of the dispersion in data reveals that when summers have been less rainy the following year's crops have lain further away from the mean.

When precipitation is separated on a monthly basis, the amount of rain that falls in the month of June (period of bloom and fruit set which coincides with maximum vegetative shoot growth) causes a generally negative tendency; the coefficient for this month is r=0.3339.

Upon analysis of the graph plotted by the regression (Figure 5), it stands out that with only one conspicuous exception, the smallest crops were obtained in the years that received more rain in the month of June, contrary to what one would logically expect.

The two-year effect (on the following crop) is the opposite in that the coefficient becomes positive (r=0.272). In this case, however, the clusters are not as defined as in the preceding figure (Figure 6).

When working with the crops recorded in above and below-average years it turns out that in "on years" there is a weak negative effect (r=0.3587) between summer rain and productivity (Figure 7). In "off years" a positive correlation is observed with summer rains in the preceding year (r=0.5015) (Figure 8).

Aggregating or splitting data in other ways, by phenological stages, cycles, pentade-based clusters, did not reveal different findings.

EFFECT OF CLIMATE ON OIL FORMATION

During the period considered (August-October) no correlation emerged between oil production and climatic pattern; all the coefficients of correlation were not significant and close to zero.

The parameter of oil formation, which is controlled chiefly by genetic matrix (Lavee and Wodner, 1990), depends only in part on the result of a set of environmental effects that are not easily disaggregated and which probably affect the speed of accumulation and maturation. During this period climatic conditions are favourable and constant in this area and would not seem to have a significant influence on oil formation.

DISCUSSION

The peculiar response to rainy periods and the year's or following year's production deserves more thorough comment. It is a commonly-held belief that summer rain improves production. However, in the environment studied, high rainfall in the month of June had a negative effect on the ongoing year and a mildly positive effect on the following year's crops. Two possible effects can be defined: a direct effect of the rain and an effect of water as a hydric resource.

Rain can reduce pollen availability, wash away stigmata and prevent pollination.

Water on the other hand could cause an effect of sudden luxuriant growth which would heighten competition between reproductive and vegetative organs, like what occurs in avocado (9a).

Obviously, any interpretation of a phenomenon depends on the validity of the hypotheses put forward. If the olive responds to improved fertility by encouraging vegetation, increased water availability could give this type of result; a response through vegetation is confirmed by the crop results for the next year. In "off years" this correlation (Figure 8) amounts to r=0.501.

Water would therefore appear to function as a regulator of vegetative growth. Stress situations are caused in adult plants by the absence of rain for long periods of time. The lowest production was recorded the year following the combination of the driest summer and a good crop (6.2 mm and 11.3 kg).

TABLE 4 : **RAINFALL (mm) IN JUNE AND DURING THE ARID PERIOD (June-August)**

YEAR	June	Summer
1968	38	143.8
1969	9.4	121.4
1970	74.8	144.2
1971	30.6	51.2
1972	8.2	45.6
1973	9	43.6
1974	22.2	126.4
1975	18.4	219.6
1976	13.4	69.4
1977	12	67.8
1978	11.6	21.2
1979	23.2	61.2
1980	23.6	94
1981	3.8	6.2
1983	41.8	177.8
1984	17.4	66.4
1985	8.6	58.8
1986	83.2	177
1987	17.6	17.6
1988	31.8	39.1
1989	6	219.4

Research has been conducted to ascertain water efficiency, depending on the frequency and volume of application, in adult trees growing in a warm Mediterranean environment characterised by pronounced aridity and has shown that the period of distribution does not have a great effect and that a large application in August (21) is enough to guarantee the positive effect of irrigation.

This information confirms that the rainfall pattern of the test area is beneficial to the olive which can take advantage of early August precipitation, which also helps to maintain some degree of regularity in growth, crops and production level.

The high temperatures reached in the summertime have been found to have a mildly favourable effect on crops, and this too can be justified by the modifications induced in vegetative growth which, by decreasing, encourages fruit growth.

This retroactive mechanism between vegetation and production, which is substantially nutritional in nature, may also be responsible for the lack of correlation between production and low winter temperatures. Some experimental evidence (Lavee, per.comm.; Navarro et al., 1990) seem to indicate that there may be a pre-induction period in the olive which influences bud development and which is also determined early in the shoot growth stage. Chilling acts as a factor that confirms successive development, becoming a necessary but not determinant condition.

CONCLUSIONS

In an environment characterised by a summer dry period that is not particularly prolonged and where winter temperatures rarely drop close to zero, the olive produces quite regularly and no specific relationships have been found between a weather occurrence, either in the annual cycle or in specific phases of tree growth, and productivity.

For an environment to be particularly suited to a given production, it has to contribute to establishing equilibria that are removed from growth extremes understood as plant survival or exuberant development. Bloom and fruiting are the result of what are endogenous equilibria for the most part and which are only prompted or permitted by exogenous stimuli.

In the trial area the mean, maximum and minimum temperatures at the different times of year do not seem to be important. The olive's temperature requirements always appear to be more than satisfied. Some data remain unexplained although they would be logical if one worked on the hypothesis that the olive is on a "temperature deficit" during the growth stage.

The most striking finding is that summer rains do not have a positive effect on the year's and following year's productivity. It is possible that summer rain, in June especially, which washes away stigmata and hinders pollination, may also heighten competition between the ongoing crop and vegetative growth, which might perhaps increase successive tree water deficiency since regular irrigation is not provided. However, the next year's crop is so far away in determinist terms that such an evident lack of correlation should not be a source of any worry.

The focus has to be placed once again on the fact that (possible) growth and production are closely linked to each other through reciprocal equilibria. The weak point of this type of research is always the same, namely that it aims to link factors that are certainly important - environmental factors for instance - to specific endogenous mechanisms for which it is not yet possible to frame univocal hypotheses.

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