Irregular Bearing and Climate in Olive

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Abstract: *Long term yield records are important reference databases useful for calibration and validation of models for climate analysis. The evaluation of olive tree yields for Jaen province, the main production area in Spain, during a 21 years period of system stasis (constancy of variety and agro-techniques), revealed (a) a remarkable interaction between rainfall and previous year production with a significant non-additive term and (b) the fact that the previous year yield does not show any descriptive power of the current-year production. These evidences raise several questions about the rightness of alternate bearing as driving variable in olive orchard models, being the time series distributed in irregular fashion among conditions of Medium (M), Low (L) and High (H) fruit load.*
In the Jaen data set, the interaction between an aleatory factor (annual rainfall) and an equilibrium determined by two biological variables (flower fertilization and previous year shoot elongation) is statistically proved. These biological variables depend on the rainfall level. As a consequence, yield time series are not auto-correlated and yield modelling should measure productive efficiency at least in 3 classes of fruit load in order to avoid the risk of finding stochastic yield frequency. So the models of olive orchard production should record previous year fruit load, current year fruit load and water availability in order to describe up to 70% of the variance within IPCC fingerprint high confidence limits (i.e. above a probability level of 0.67).
Keywords: *Olea europea L., Fruit bearing, Production models, Water use efficiency.*

Riassunto: *Le serie produttive a lungo termine sono le basi di dati sulle quali supportare modelli e studi sull'impatto climatico. Nell'olivo la valutazione della produzione media ettariale del territorio di Jaen, principale provincia olivicola di Spagna, durante 21 anni di stasi del sistema (stessa varietà, stesse agrotecniche), ha rilevato una marcata interazione della produzione con la precipitazione annuale e la produzione dell'anno precedente, con un termine non-additivo significativo. Al contrario la produzione dell'anno precedente non ha nessuna capacità descrittiva se presa da sola. Queste evidenze pongono dei limiti al valore dell'alternanza a livello regionale come variabile guida nei modelli di previsione della produzione olivicola, essendo la serie temporale distribuita in modo assai irregolare fra le condizioni di media (M), bassa (L) ed alta (H) carica produttiva.*
Nel dataset di Jaen è statisticamente provata l'interazione tra un fattore aleatorio (la precipitazione annuale) ed un equilibrio biologico determinato dalla fertilizzazione dei fiori e dall'allungamento del germoglio. Queste variabili biologiche dipendono da un livello di pioggia determinato. Come risultato le serie produttive non sono autocorrelate ed i modelli produttivi dovrebbero ripartire le produzioni in almeno tre classi di carica fruttifera onde evitare il rischio di incorrere in una frequenza stocastica delle produzioni. In queste condizioni, note la produzione dell'anno precedente, lo stato di carica corrente e la disponibilità idrica è possibile stimare la produzione fino al 70% della varianza entro limiti accettabili nella fascia di confidenza alta dell'IPCC (al di sopra di un livello critico di probabilità di 0.67).
Parole chiave: *Olea europea L., Carica fruttifera, Modelli produttivi, Efficienza idrica.*

Abbreviations: H, M , L high, medium and low Fruit Load, LTE long term experiment, FL fruit load in kg ha-1 and RF annual rainfall in mm, IPCC Intergovernmental Panel on Climate Change.
Abbreviazioni: H, M, L alta, media e bassa produzione, LTE esperimento a lungo termine, FL produzione in kg/ha, IPCC Comitato Intergovernativo sui cambiamenti climatici.

INTRODUCTION

Time series of yearly mean yield in olive groves taken at farm or regional level show an high variability that has been defined as "alternate bearing" in a number of issues (Bongi *et al.* 1995, Loreti and Natali, 1991. Ben-Gal et al. 2011). This variability, testified for example by coefficients of variation often above 50%, is too high to achieve a mean separation into components (trend, seasonality, slow and fast variation and so on) so giving a strong limit to obtain predictive models of olive production.

A minimal area that could be related to gridded climatic models is much wider than a single orchard (0.5 by 0.5 degrees of lat long) or a parcel in an experiment, and climate impact studies require coherence in response linked to probabilities of a given set of driving variables in a range higher than 0.67 if the process is due to various possible causes (Parmesan and Yoe, 2003). This effects becomes a

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Received 11 June 2011 accepted 5 October 2011

'fingerprint' in IPCC schedules and high confidence range is limited to the interval over 0.67, accounting in this way the decimal proportion of cases that are in agreement with the variation in a subset of variables. With this boundary every model that predict below this probability limit is not important but can retain scientific value. In other practical activities a fingerprint coherence is perceived as "reliable" and this corresponds to model accepted in farm and olive mill catchment practices. We should however admit that possibly regional level studies are a summary of experiences and that the mean value for a single year represents a sort of meta-analysis, without knowing single year observational error. Above this limitation, economic trends are linked to entire regions for gross production and require coherence too.

Much more is known about the biology of olive in isolated field experiments where, in order to force the mean separation, strict sampling procedures are applied to parcels, but coherence with territorial scale behaviour of plant populations is not guaranteed. At design level the number of observations increases up to the inclusion of time series in parcels or the use of cumulative production as an extra variable.

At single shoot level, the notion of alternate bearing in analogy with AC current or pendulum periods is described by a regular fluctuation between statuses and a sequence H, L, H is sufficient to determine amplitude and phase of the variable. In olive tree studies the amplitude is reported as sensitivity to alternance and the period is assumed to be 2 years using H for high load and L for low fruit load cases. Caffeic acid–like substances and fruit shoot load with fruit bio-phenols have been suggested as a possible mechanism of alternate bearing acting at single shoot level (Lavee *et al*., 1986, Palese et al. 2010); this evidence was tested using substitution treatments in shoots. This qualitative description can be depicted in quantitative terms as a locus in a plot of current year production against the previous year one, with both X Y axes maximum coinciding with maximum production; the algorithm gives a zero in the year after a theoretical maximum was attained in X or Y, with all intermediates falling on a line with a slope -1. In this hypothesis the system may remain indefinitely in mean condition M until some perturbation occurs that triggers H or L condition.

Published experiments are often ranked by selecting an H, M or L condition (Dag *et al*., 2010) but the generalization of relationships like crop coefficients would require their relative frequency and a study of variability among fruit load classes (Ben-Gal *et al.*, 2011, D'Andria *et al.*, 2004, Pastore, 1940), even at single tree scale. The feasibility of experimental conditions measures the transition between experiments and trials. In terms of coherence this as a variable impact on actual rates of productive plantations. The sequence of states between different levels of fruit load is irregular and there is no grant about the stability of plot plant experiments when propagated at trial level. Is this sequence able to be apportioned to an algorithm like a line with slope -1? Is it possible to work out a stable predictor of olive production at regional level? Inherent instability of fertility in the shoot has also been proposed (Martin, 1990), but this would lead to an uniform distribution and to stochastic trends if propagated at higher level.

In this issue we test a reversed model at the lowest resolution spatial level in order to test production statistics in a region. Most of the uncertainty has been hypothesized to originate from random errors or systemic in-homogeneity but this possibility must be cleared using long term series. Farm and province scale studies include plantation age effects, with plantation to first productive crop interval, mature orchard duration and senescence, in succession of discrete steps, but their relative lengths vary upon treatments and determine treatments classes. Seldom olive cultivation areas are in steady state conditions for the variable effects of new plantations or product support incentives.

MATERIAL AND METHODS

This LTE (Long Term Experiment in the common meaning), is a time series from Andalusia, the major autonomous region of southern Iberian peninsula, in the province of Jaen described in Table 1, and was collected between 1945 and 1966 (Cantero de Andres, 1971). This case study coincided with a period of relative stasis of olive economy in Spain (Camilleri, 1984). The integration to a large area should buffer single orchard variations and show only synchronous

Whole area: 13496 Km^2
Mean location: 38 N and -3.5E
Olive area: 572627 ha (95% with Picual)
Landscape: hilly slopes
mean slope: 8 -15%
main cropping aspects: traditional, non intensive, rain fed, single-cultural olive

Tab. 1 - Jaen province main characters.
Tab. 1 - Principali caratteristiche della provincia di Jean.

sequences or a stable mean (Loreti and Natali, 1991, ex *Cantero de Andres ibidem*). For ease of reference in further studies the time series of olives yield (fresh fruits weight per hectare) and yearly rainfall (mm) are listed in Table 2.
Statistical analysis was used to test the existence of annual variability and auto-correlation with the previous year production D, in the hypothesis of a strong effect of alternate bearing. Graphical functions and statistical tests from *lm* and *ts* functions of R version 2.7.0 package has been adopted (R Development Core Team, 2008).
The software library "*hsaur*" was also loaded in R to test multiple regression (Everitt and Thorton, 2006). To test interaction structure a model series was created using 0.25, 0.5 and 0.75 quantiles with the same grid spacing and numerosity of the original series and variance of internal classes was tested. Quantile separation was done using confidence intervals of subsets and Montecarlo generators driven by the standard deviation of the original subset. The paucity of data in their original ranking in H, L and M classes forbids the use of sub-subsets for calibration. The difference of cumulative rainfall sensitivity on different production classes was tested using R library "*gap*" (Zhao, 2007).

Y	Kg	D	mm
1	1931	363	691.0
2	1965	1931	973.7
3	965	1965	762.1
4	988	965	420.3
5	638	988	354.6
6	2177	638	707.9
7	1500	2177	693.7
8	820	1500	338.2
9	1209	820	513.2
10	890	1209	660.9
11	1761	890	670.7
12	1897	1761	503.4
13	1159	1897	567.4
14	1863	1159	830.4
15	1886	1863	1032.2
16	1420	1886	757.1
17	1284	1420	747.8
18	3000	1284	1057.4
19	113	3000	737.5
20	784	113	588.7
21	2750	784	912.5

Tab. 2 - The series of 21 Years (Y) of consecutive production in Kg/ha (Kg) and annual rainfall in mm (mm). For statistical purposes D is the previous year production in the same units (rewritten from Cantero de Andres, 1971).
Tab. 2 - La serie di 21 anni di produzione consecutiva in Kg/ha (Kg) e la precipitazione annua in mm (mm). Per scopi statistici D è la produzione dell'anno precedente espressa in Kg (rielaborazione da Cantero de Andres, 1971).

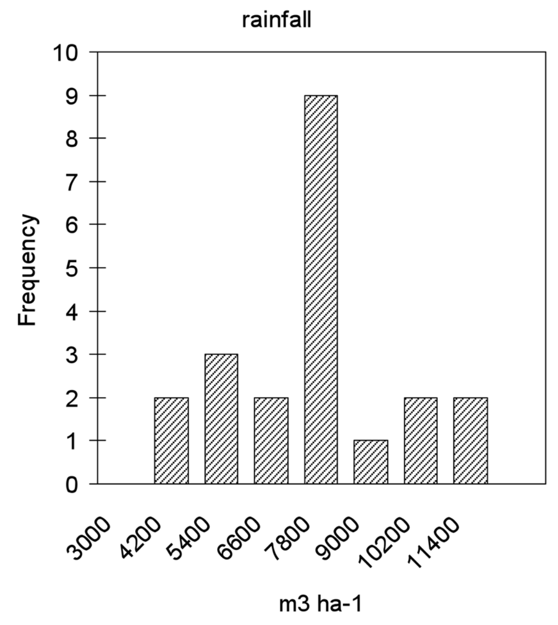

Fig. 1 - Distribution of rainfall in 21 Years in the province of Jaen. It was here considered in mm (mm, (m^3 ha-1)/10).
Fig. 1 - Distribuzione della pioggia nella serie di 21 anni a Jaen. In questo testo l'unità è in mm (mm, (m^3ha-1)/10).

RESULTS
The stasis in the period offers an unique opportunity of a quite long series with regional smoothing effects on single site variations, but even in this condition the sequence of fruit bearing is markedly irregular. Sectioning the series in 3 quantiles for fruit production (i.e. high H, Medium M and low L),

produced the sequence H, H, L, L, L, H, M, L, M, L, M, H, M, H, H, M, M, H, L, L, H. This series is not synchronous with previous year state nor with precipitation classes and it is hard to trust autocorrelation. The traditional view of a biennial bearing was tested with a model that takes into account only the effect of the previous year production. This model did not gave a significant output (adjusted R-squared of 0.007076 and high probability of null hypothesis – F statistic: 1.143 on 1 and 19 DF, p-value: 0.2985). If it is also considered that autocorrelation tests failed to find significance it is possible to reach the conclusion that the previous year charge is not an adequate predictor of olive charge time series. In Figure 3Tl we observe quite a random distribution below and above the locus of the theory of alternate bearing quantitative equilibrium (i.e. the line with slope -1). Parametric measures of fallacy are done by "sigma" in lm procedure of R and corresponds to the square root of estimated variance of random error, 689.2 kg on a mean tendency of 1420 kg ha-1. In coherence terms this would equal a wrong assignment in one case over 2 with this dataset.
The time series of the yearly rainfall for Jaen province shows a mean value of 780 mm, but production in fresh fruit per ha (kg) varies widely and the mean is not the most frequent datum but is far from an uniform distribution (Fig. 2). A linear

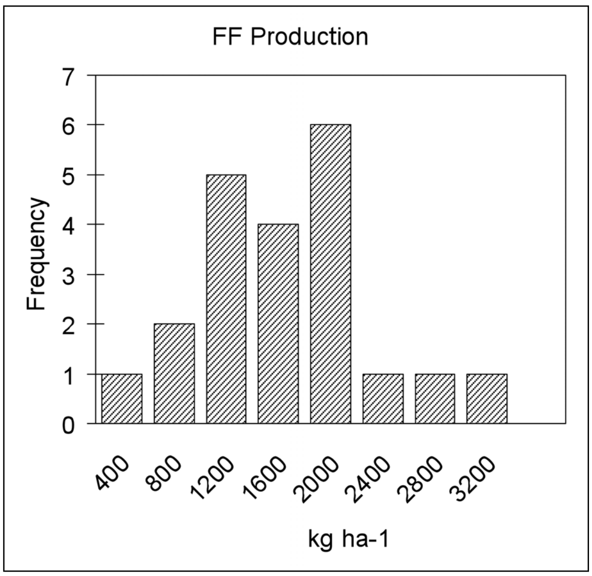

Fig. 2 - Frequency of Jaen province production in Kg ha-1 (fruit fresh production). The mean is not the mode and tails reveal system apparent stochastic boundaries.
Fig. 2 - Frequenza della capacità produttiva in frutti freschi di olivo della provincia di Jaen. La media non è la moda e si verifica una apparente stocasticità dei limiti.

Model	F	Pr(>F)	
0/2	20.524	0.00 0259	***
0/3	19.636	3.81 e -5	***
1/2	6.960	0.0167	*
2/3	9.792	0.001482	**
1/3	9.729	0.001525	**

Tab. 3 - Analysis of variance among production models in a partial contrast (/) matrix. The model of previous year production D on fresh fruit production (0) is compared (/) to different alternatives: the effect of rainfall (mm) (1), this last with previous year production D (2) and with model (3); model 3 is the case (2) with interaction D:mm. Variance within mm models is also considered; regression lines are significantly different but the main effect appears when the non additive term is added; missing comparisons are redundant and the *** in 0/- appears because model 0 (alternate bearing) does not converge so that any significant model would give an high probability of difference. The asterisks mean significance level at 5% (*), 1% (**) or 0.1% (***) of probability.
*Tab. 3 - Analisi della varianza tra i modelli presi in esame in matrice di contrasto (/). L'effetto della carica dell'anno precedente D sulla produzione è il caso (0) e la barra(/) indica il contrasto con la pioggia (1) sulla produzione, con la pioggia e con D (2), e con l'interazione D:mm (3) sulla stessa variabile. La varianza entro i modelli mm è esaminata; i modelli sono tra loro significativamente differenti, ma l'aumento principale avviene nel confronto con il modello con interazione. I casi mancanti sono ridondanti e il valore *** nei confronti 0/- è dovuto alla non convergenza del modello 0 (alternanza produttiva), in misura tale che ogni modello significativo avrebbe comunque una alta probabilità di differenza. Gli asterischi(*), (**) e (***) indicano 5%, 1% e 0.1% di probabilità dell'ipotesi nulla.*

model of rainfall effect on production is appropriate but describes 36% of the variance and is useless to describe production due to the large estimation error (F statistic was 12.61 on 1 and 19 DF, with a p-value: 0.002133 that is significant but deceptive, in the possibility of an high probability of missing representation ability near a critical border for coherence if we admit a perception that should require at least 2 cases right over 3 trials) (Fig. 3Tr).
The significance of R2 was determined after testing the presence and stability of a zero production rain fall near to 300 mm; R2 is adequate after calibrating a zero production near 300 mm (thus having a response linear with intercept zero). With this correction the R2 measures the coefficient of determination, but the forecast error is too high to be useful. The sigma of this set is 562 kg per ha and the experimental rate of fallacy is about one case every 3.
The model with the inclusion of previous year

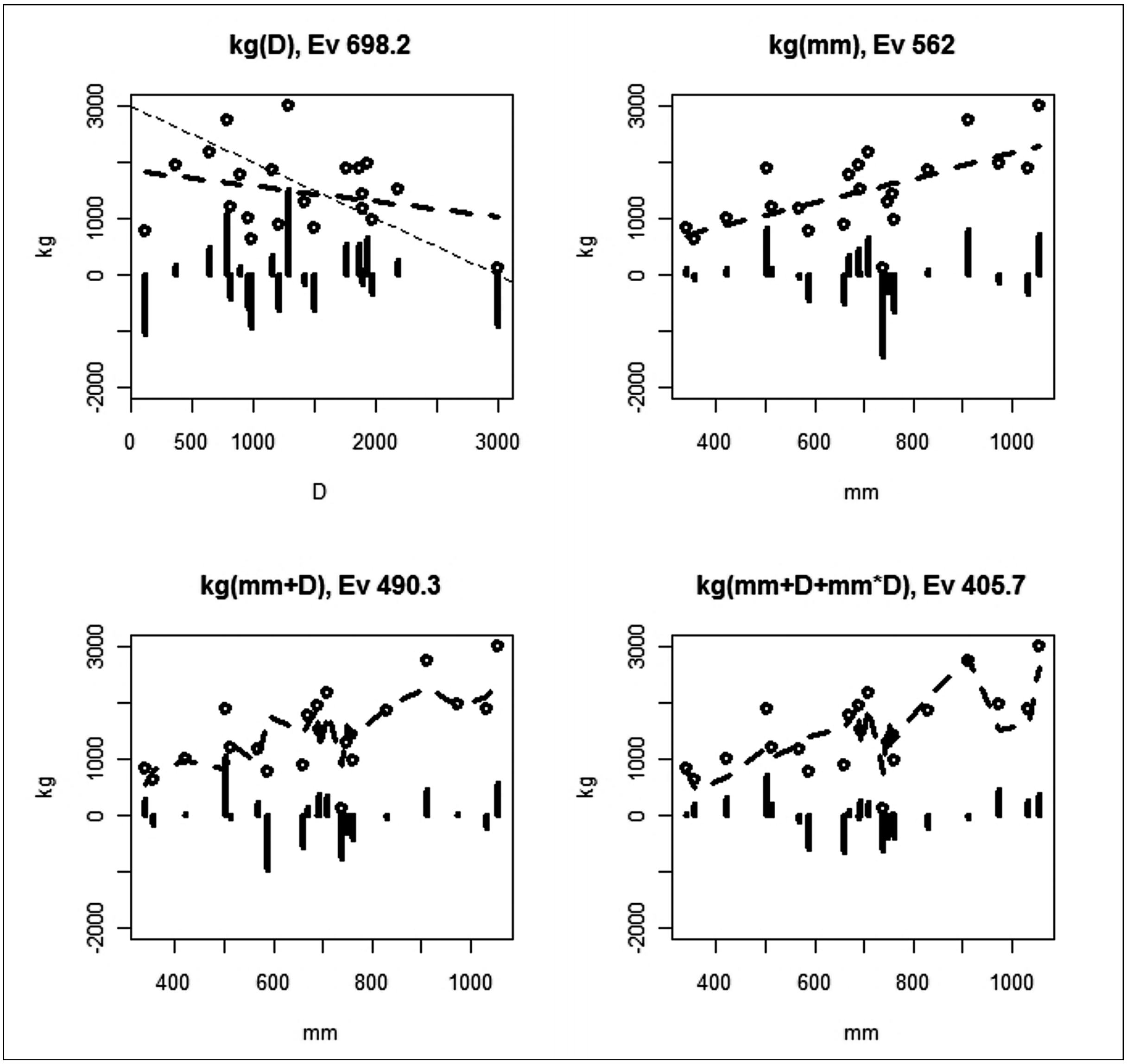

Fig. 3 - Top left (Tl) is testing the effect of alternate bearing D as an independent variable for production (kg); thin step line draws a theoretical line of perfect control, in all plots bars and tick line represent residuals and regression line. Top right (Tr) tests the effect of cumulative rainfall on kg without alternate bearing. Bottom left (Bl) is a bilinear hypothesis with both mm and D and Bottom right is the same with D*mm interaction. Ev stands for squared root of estimated variance of random error (sigma in R language).

Fig. 3 - Il grafico in alto a sinistra (Tl) misura l'effetto dell'alternanza (D) sulla produzione come variabile indipendente: la tratteggiata sottile rappresenta la linea teorica di perfetto controllo; in tutti i grafici le barre e le tratteggiate spesse rappresentano i residui e la regressione. Il quadro in alto a destra (Tr) prova l'effetto della pioggia cumulata sulla produzione senza l'alternanza di produzione. Il quadro in basso a sinistra (Bl) prova una regressione bilineare con D e mm e quello in basso a destra (Br) lo stesso modello con una componente non additiva. Ev rappresenta il valore della radice quadrata della varianza dell'errore casuale (sigma nel linguaggio R).

production, D showed a rise of R2 from 0.36 to 0.51 and the significant difference of models in the analysis of variance (anova, Table 3) was significant, thus meaning a better description (Tab. 2), in comparison with the single-year yield alone. This may lead to the conclusion that the D parameter alone has no mean separation power but cumulative rainfall of the year has such a power, and, within a given rainfall class, there is sensitivity to previous year fruit load. Residuals analysis then has an high chance of failure in production forecast also after this improvement (Fig 3Bl). The inclusion of an interactive term mm*D raised again R2 to 0.67 with a F-statistic of 14.55 on 3 and 17 Degrees of

Coefficients:	Estimate	Std.Error	t St.	Pr(>|t|)	
(Intercept)	-2.82 6e+03	1.091e+03	-2.59	0.019070	*
D	1.946e+00	7.920e -01	2.457	0.025076	*
mm	7.172e+00	1.597e+00	4.492	0.000321	***
D* mm	-3.412e -03	1.119e -03	-3.05	0.007263	**

Res.SE	DF	Mul.R2	R2	F val.	Pr(>F)
405.7	17	0.7197	0.6703	14.55	5.986e -05

Tab. 4 - Linear model of fresh fruit production with annual rainfall (mm) including the interaction (D*mm) as non additive term. signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05.
*Tab. 4 - Modello lineare della produzione in frutto fresco con la pioggia annuale, includendo l'interazione (D*mm) come termine non additivo.*

freedom, with a p-value of 5.986e-05 with significant student t (Table 4, Fig. 3Br). This level of R2, being yield a collinear function only in this survey trial, whereas in orchard experiments it is covariate of many other independent variables, and subject to curvilinear relationships, is probably close to an optimum, considering a whole district and the lack of any other information. The relationship is finally adequate and satisfies the coherence with a fallacy of 1 case over 7 and a sigma of 405 kg ha-1. In the selected time series 3 years over 21 fail prevision test, but we must add many other aspects that were unreported, like years with frost or years with unexpected variation in fertility control due to heat shock or spring drought. It was evident however that a non-additive term, given by the interaction of rainfall with previous year production, produced a significant increase of prediction ability. The analysis of variance among models determined the significance of combinations including term D but only when it was included in multiple regressions with rainfall (Table 3).

The separation of production data in upper (H) medium (M) and lower (L) quantiles produced 3 different regression lines versus cumulative rainfall that well explain the non-additive effect. H status is more sensitive than the M or L to drought and an invariant locus exists near 880 mm (Fig. 4). To obtain a model suitable for production forecast in a given condition, the knowledge of this kind of behaviour is therefore required and more specifically the knowledge of LTE and 3 sensitivities. This LTE is only useful for the combination under study, that should hold as far extensive as rain-fed cultivation is concerned. This result highlights a structured response to the combination of 2 independent variables rather than a chaotic structure. The Chow test of regression slopes resulted highly significant (Tab 5) and the model has got enough sensitivity to partition residual variance and water sensitivity into secondary determinants for local effects.

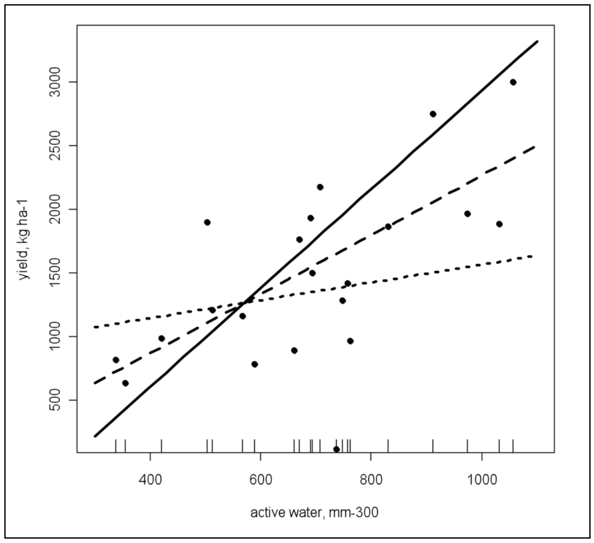

Fig. 4 - Annual rainfall and production of olives interact due to a varied sensitivity. The useful precipitation or active water is the actual level minus 300 mm m-2. Solid line depicts H status, step line M, and dot line L respectively. Rug plot on rainfall active fraction is a measure of uniformity.
Fig. 4 - Interazione tra carica e precipitazione utile (mm – 300) o acqua utile. La linea continua rappresenta l'anno di carica H, la linea a tratto breve l'anno di produzione media M e la linea punteggiata l'anno di scarica L. Il grafico a barre brevi indica la distribuzione della pioggia utile nella serie.

The diagram in figure 5 represents an hypothetical layout of the LTE multiple correlation. In water limited environments there was a tendency to fruit drop under water stress that diminished fruit

F value	DF 1	DF 2	Pr(>F)
7.501e+01	2	48	1.690175e-15

Tab. 5 - Chow test between H and L statuses. The coefficients of rainfall on production of olive orchard with low and high fruit load are physically different.
Tab. 5 - Test di Chow sui coefficienti idrici negli stati H e L. Questi coefficienti idrici dell'oliveto in condizioni contrastanti sono differenti fisicamente.

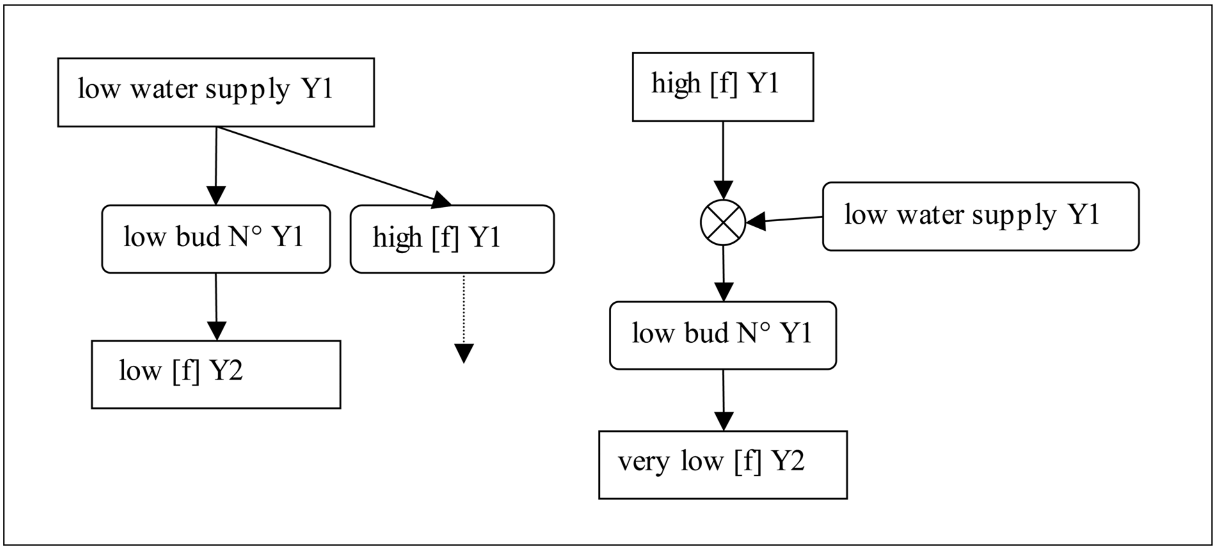

Fig. 5 - Diagrams of control in olive tree irregular bearing: the network on the left represents a feasible interpretation of LTE of Cantero de Andres (1971), where the dotted arrow is for fruit natural drop that follows water stress. It is also depicted the current biologist view in which the fruit concentration [f] should have exerted the main control on next year loading, the [f] Y2.

Fig. 5 - Schemi di controllo della irregolarità di carica nell'olivo: la struttura a sinistra rappresenta una ipotesi realistica della LTE di Cantero de Andres (1971), nella quale la freccia punteggiata rappresenta la cascola di frutti dovuta allo stress idrico. È anche rappresentata a destra la opinione biologica corrente che prevede che la concentrazione di frutti eserciti il controllo principale sulla carica dell'anno successivo.

concentration, [f], in year 'one', Y1. The interactive term of [f] Y2 with [f] Y1 is due to the action of water limitation on bud number. The hormonal action scheme by some growth inhibitor released from fruits or from water stress signals (Lavee et al., 1984), that has been found on experiments with uniform twig samples, is depicted on the right diagram and would have produced a strong autocorrelation between [f] Y1 and next year load, and a possible effect of water supply as secondary cause if this framework was maintained at population level. In case the [f] should persist in order to affect bud number. Eventually the absence of this relationship in regional trends was probably an artefact due to unreliable sampling for shoot heterogeneity.

In the Jaen province time series this set of causes seems to be bound to non-additive effects of rainfall on fruit production. In reversed models one should expect better cumulative performance if a rain fed system is fluctuating between H M and L statuses than if it is maintained in M condition if coincides with yearly rainfall fluctuations.

CONCLUSION

The analysis of production series in Jaen converges to the limits of quantitative effects of fingerprints after a simple bilinear model taking into account the interaction of rainfall and previous year production. This can be due to the compensative effects of the large areas cumulative production but there is no evidence of stable mean. A status of mean M can result from a fifty-fifty of L and H areal distribution or from the prevalence of M; in this case M should prevail in frequency; however this time series has got a low frequency of M and this supports the idea of a synchronicity across the area, without memory effects.

Alternate bearing in olive using single shoot experiments is a wrong argument to describe irregular bearing and this attribution mistake is possibly originating by a confusion of causes between small scale experiments and regional trends. A comparison scheme with biologist's current opinion can clarify this model as seen in comparison with substitution experiments.

This is a first contribution to the analysis of statistical stability of olive fruit production, but many other clues, like rain seasonality, plantation density and varietal effects require further analysis.

ACKNOWLEDGEMENT

The activity has been made possible by project Agriscenari, a grant MIPAAF after D.M. 8608/7303/2008.

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