Spatio-temporal dynamics on a plot scale of cocoa black pod rot caused by Phytophthora megakarya in Cameroon

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Relationships between cocoa *Phytophthora* pot rot disease and climatic variables in Cameroon

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Relations entre l'incidence de la pourriture des cabosses due à *Phytophthora* et plusieurs variables climatiques au Cameroun

Abstract

Phytophthora pod rot disease causes almost 30% loss in world cocoa production. Epidemiological observations showed that the disease appears when there is conjunction between the presence of fruit on trees, whatever their growth stage and when the rainy season has begun. The effects of environment on the epidemic are not well-known in cocoa producing zones. The aim of this study was to assess and quantify the influence of rainfall and temperature on the temporal development of the disease in the cocoa producing areas of Cameroon.

The study was conducted in three regions of Cameroon (Mbankomo, Goura and Barombi-Kang). One hundred trees were observed in each site. Disease incidence and crop production data were collected weekly. Rainfall and temperature data were collected daily. Field observations were made over a period of three years (1999-2001). Autocorrelations, cross-correlations and multiple regression analyses were used to establish relationships between disease incidence and the environmental variables.

The study showed that pod rot incidence is associated with to rainfall. There is not a univocal relationship established between the two variables. The disease symptoms were expressed one to two weeks after rainfall events. This is a contribution to the creation of a disease warning system to better advise cocoa farmers about disease risk. The present study is, therefore, an important step towards a better understanding of quantitative relations between disease incidence and the environment.

Keywords: Cross-correlation; epidemic risk; integrated protection; *Phytophthora megakarya*; *Theobroma cacao*.

Résumé

La pourriture des cabosses du cacaoyer due à divers *Phytophthora* cause plus de 30% de pertes de récolte au niveau mondial. Des observations épidémiologiques indiquent que cette maladie apparait lorsque les fruits sont présents sur les arbres, quelque soit leur stade de développement, et lorsque la saison des pluies a débuté. L'influence du climat sur le processus épidémique n'a été, pour le moment, que peu étudiée dans les zones de production. L'objectif de ce travail est de mesurer et de quantifier l'influence des pluies et des températures sur le développement temporel de la maladie dans plusieurs zones de production du Cameroun.

Cette étude a été conduite dans trois sites du Cameroun (Mbankomo, Goura et Barombi-Kang) ; cent arbres ont été observés par site. Les données concernant la maladie et la production ont été collectées chaque semaine, alors que les variables climatiques ont été collectées tous les jours. Les données ont été recueillies durant trois années consécutives (1999-2001). Des autocorrélations, des corrélations croisées et des régressions multiples ont été utilisées pour mieux comprendre les relations entre l'incidence de la maladie et les facteurs climatiques.

Cette étude montre clairement l'incidence de la pluie sur l'intensité de la maladie. Cette incidence se manifeste une ou deux semaines après les pluies. Ce travail jette les bases d'un modèle d'avertissement agricole afin de mieux conseiller les agriculteurs dans la gestion des risques épidémiques. Il s'agit d'une importante étape pour mieux comprendre les relations quantitatives entre l'intensité de la maladie et les variables climatiques.

Mots-clés: Corrélations croisées; risque épidémique; protection intégrée; *Phytophthora megakarya*; *Theobroma cacao*.

Introduction

Pod rot, caused by different species of the genus *Phytophthora*, is widespread in all cacao producing countries. Worldwide, the most common species is *P. palmivora*. In Cameroon, studies revealed the existence of a single species, *P. megakarya* , that was responsible for the disease (Nyassé, 1992). Although this disease can affect different organs such as the roots or the trunk, it mainly attacks fruits. The different *Phytophthora* species all cause the same symptoms on pods, namely rotting black patches that sometimes spread to the entire fruit. Damage from pod rot can be up to 30% of the world harvest every year.

Disease expression in the field is influenced by numerous factors, both environmental and genetic such as environmental conditions (rainfall, wetness and temperature), pathogen survival and dispersal, pathogen species and strain involved, as well as host resistance (Tarjot, 1964; Akrofi et al, 2003; Cilas et al, 2004). All these factors can interact to favour or to restrict disease development. For example, some genotypes of *Theobroma cacao* may appear resistant in an environment and susceptible in other ones. This phenomenon is known as “genotype x environment” interaction (Cilas et al., 2004).

The present study focuses on the incidence of environmental factors on dynamics of the disease. Whether in Cote d’Ivoire (Tarjot, 1964, 1967), Ghana (Asare-Nyako, 1973), Cameroon (Muller, 1974a, 1974b), Jamaica (Henry, 1977) or Nigeria (Gregory and Maddison, 1981), epidemiological observations showed that *Phytophthora* pod rot appears when there is a conjunction between the presence of fruit on trees, whatever their growth stage, on one hand and rainy season on the other hand. The effects of climate on the epidemic process are only known in a macroscopic approach in cocoa producing zones (Tarjot, 1964). In Cameroon for example, the incidence of disease tends to be higher in some agro-ecological zones with a mono-modal rainfall regime, compared to those with a bi-modal rainfall regime (Ndoumbè-Nkeng, 2002).

Similarly, a positive correlation has been found between the rate of pod infection and the potential production, implying that the environmental conditions determining both disease incidence and production capacity are similar (Muller, 1974a; Despréaux, 1988). However, this observation does not take into account the climactic variations observed for the whole production period, such as the alternating dry and wet periods and their impact on the process and intensity of the epidemics. Knowledge of the effects of climatic variations on pod rot incidence is useful, particularly to plan fungicide applications.

The objective of the study was to assess and quantify the effects of rain events and temperatures on the temporal development of the disease in the cocoa producing areas of Cameroon, like it was done on other crops (Rapilly, 1991). The questions addressed were (1) what are the relationships between climatic factors and disease expression? (2) Is there a threshold for these factors above which the disease occurs?

Materials and Methods

Study sites and experimental design

The study was conducted in three locations in Cameroon: Mbankomo (Centre Region, Mefou-et-Akono Division; coordinates: 3°78’0’’N and 11°38’0’’E), Goura (Centre Region, Mbam-et-Kim Division; coordinates: 4°55’60’’N and 11°45’0’’E), and Barombi-Kang (South-West Region, Meme Division; coordinates: 4°34’40’’N and 9°27’21’’E).

Mbankomo and Goura are situated at altitudes of 730m and 480m, respectively and belong to the agro-ecological zone with a bi-modal rainfall regime, characterised by two dry (from December to February and from June to August) and two wet seasons (from March to May and from September to November). The soils are ferralitic, average (base saturation of 35%)

to highly (base saturation of 20%) unsaturated. Barombi-Kang, altitude 180m, belongs to an agro-ecological zone with a mono-modal rainfall regime. Barombi-Kang is characterised by a highly humid and hot climate, with a long wet season (March to November) and short dry season (December to February).

The sites chosen were thought to be representative of the agro-ecological conditions suitable for optimal cocoa production. On these sites, many farmers were prepared to allow experiments in their cocoa fields. Experimental plots were selected on the basis of accessibility, size and maintenance of the farm. Cocoa plantations studied were about 15 years old at Barombi-Kang and Goura and over 25 years of age at Mbankomo. The site at Barombi-Kang had traditional cocoa varieties (*Amelonado*). There are hybrids cocoa varieties (*Amelonado x Trinitario*) at Mbankomo and mixed traditional and hybrids varieties at Goura.

At each of the three plots, 100 trees were randomly distributed. The plot was surrounded with a phytosanitary barrier made up of two rows of cocoa trees, to prevent chemical treatments and pathogen spread from neighbouring farms. For the purpose of field observations, the observed trees were divided into three levels: 0–0.5 m (level 1), 0.5–1.50 m (level 2) and > 1.50 m (level 3). Inside the same plantation, the spacing among trees varied from 2.5 x 2.5 m to 3 x 3m, corresponding to tree densities of 1111 to 1600 cocoa trees ha^{-1}.

Data collection

Rotten pods (caused by *Phytophthora* sp., *ROT*), wilted fruit (early desiccation, *WILT*), fruit damaged by rodents (*DAM*), fruit infected by diseases other than *Phytophthora* pod rot (*OD*), cherelles (fruit ≤ 4 cm length, *CHER*), young pods (fruit > 4 cm length but not yet at adult stage, *YP*), adult pods (but not yet mature, *AP*), and healthy mature pods (*MP*) were counted weekly. These variables were chosen for weekly estimation of pod rot rate (Number of rotten pods / Number of all the pods).

At each site, a rain gauge (high: 150 mm) was installed in an open area and two thermometers were placed outside the plantation and under the cocoa tree canopy within the plantation, respectively. Rainfall (mm) and temperature (°C) data were collected daily.

Observations were made over a period of three years (1999-2001). Disease status and production data were collected weekly from mid-April, when the first pods appeared on the trees, to the end of the production season (mid-November) each year. In total, there were around 30 weeks of data collection per site and per year. After each round of observation, rotten or wilted fruit, as well as fruits damaged by rodents and other diseases were harvested from trees and removed from the farms.

Based on the data collected, the pod rot incidence (*PRR*), mean temperature and total rainfall were calculated from the variables measured in the field.

The calculation method for the weekly pod rot incidence (*PRR*), was adapted from the formula used by Berry and Cilas (1994b) and De Jesus (1992). The losses due to *PRR* were estimated using the potential production:

$$PRRi = \frac{ROTi}{(ROTi + MPi)} * 100$$

where $PRRi$ = Pod rot rate at the week *i*

ROT_i = number of rotten pods at the week *i*

MP_i = number of mature pods at the week *i*

The minimum surrounding temperatures (*SMinT*) and those under the cocoa trees canopy (*UCMinT*), and the maximal ones (*SMaxT*, *UCMaxT*), expressed in degrees Celsius, represent respectively, the averages of minimal and maximal temperatures of the week (7 days). The mean temperatures (*SMeanT*, *UCMeanT*) are the averages of both weekly minimum and maximum temperatures. The daily thermal amplitude (*Amp*) was calculated, by taking the difference between maximum and minimum daily temperatures.

Similarly, total rainfall per week (*RAIN)* was the cumulative rainfall calculated from the daily rainfall.

Statistical analyses

For each derived variable, an analysis of variance (ANOVA) was done per site and per year. The data for three years were pooled to test the site and year effects. Logarithmic or angular transformations were sometimes necessary, to meet the requirements of the general linear model, particularly the homogeneity of variances.

When the test associated to the ANOVAs (F-test) lead to rejection of the null hypothesis, the means were compared by contrasts (Gomez and Gomez, 1984; Tomassone et *al*., 1993).

Set of variables measured each year for 30 successive weeks (*T*), could be seen as chronological series, with week as the lag period unit, meaning that the sequence of measurements did not follow a random order. Auto-correlations of variables were estimated with the purpose of understanding disease progress over time, the autocorrelation being defined as the correlation calculated between a series and a lagged version of itself. If the correlation coefficient is calculated for all lags k=0,1,2...N-1 the resulting series is called the autocorrelation series or the correlogram. Cross-correlations were calculated for different lags to identify the lag which allows to maximise the correlation between rainfall and PRR incidence, *i.e.* to determine the number of weeks between rainfall and disease expression.

The autocorrelation coefficient ρ, of lag (or *period*) k was calculated, considering the T-1 pairs of observations $(y_1, y_2), (y_2, y_3), \ldots, (y_{T-1}, y_T)$, in the following manner (Box and Jenkins, 1976 ; Tomassone et *al*., 1993 ; Bourbonnais, 2000) :

$$\rho_k = \frac{\sum_{t=1}^{T-k}(y_t - \bar{y})(y_{t+k} - \bar{y})}{\sum_{t=1}^{T}(y_t - \bar{y})^2}$$

$\bar{y}$ represents the mean of the series.

All auto-correlation coefficients (ρ_k) were calculated with a lag k - k varying from 1 to 4 weeks (Bourbonnais, 2000; Quenouille, 1949; Ljung and Box ,1978).

Cross-correlations were computed to evaluate the link between pod rot rate and the environmental variables. The cross-correlation r of k's lag between two series x_i and y_i is defined as follows (Bourke, 1996):

$$r_k = \frac{\sum_i (x_i - \bar{x})(y_{i-k} - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\sqrt{\sum_i ((y_{i-k} - \bar{y})^2}}$$

Where $i = 0, 1, 2, \ldots T$-1 in week; $\bar{x}$ represents the mean of a series x_i and $\bar{y}$ is the mean of the series y_i. Multiple regression analysis was done to find the most parsimonious model to predict pod rot rate. In order to suppress the auto-correlation present in the series relative to disease incidence (*PRR*), the difference between two time points was used for the analysis (Kendall, 1976). An angular transformation of the variable *PRR* (Arcsine$\sqrt{PRR}$) was used to ensure the homogeneity of variance which is a requirement of general linear model (Draper and Smith, 1981).

These analyses were carried out per site and per year and subsequently per site with combined the data of the three years. Data were analysed using Statistica and SAS (SAS, 2001), with REG and GLM procedures.

Results

The evolution of temperature, quantity of rainfall, and PRR incidence was monitored during three years (Figures 1 to 3). Temperature is not presented because it was more or less constant within each site and within each of the three years.

Temperature and rainfall

In Mbankomo, 2001 was cooler than 1999 and 2000 ($P < 0.05$). The reverse was observed in Goura where 2001 was warmer than the two previous years. In Barombi-Kang annual temperatures were not significantly different ($P>0.05$) between years (Table 1). At the three sites, annual rainfall (in mm) varied among years. In Mbankomo and Barombi-Kang, significant differences ($P<0.01$) in rainfall observed in 1999 and 2000 was observed. In addition, the year 2001 was the wettest in these two locations. In Goura, rainfall varied significantly during the three years ($P<0.001$) (Table 1). Mbankomo was the site where the lowest temperatures were recorded for all years. The temperatures at Goura and Barombi-Kang were similar. Barombi-Kang was the site that had the greatest total quantity of rainfall during the three years, and Goura had the lowest, with rainfall below seasonal norms in 2001. Difference of temperature and rainfall means between Mbankomo and Goura (though situated in the same agro-ecological zone) was the outstanding point in the observation of environmental variables.

Production and Phytophthora pod rot rate

The number of healthy pods per tree, for each site and each year is shown in Table 2: in Goura in 2000 (21.31 fruit/tree), in Barombi-Kang in 1999 (21.9 fruit/tree) and in 2000 (19 fruit/tree). This was a high number of healthy pods per tree as compared to the average national production of 10 fruit/tree.

In each site, pod rot incidence (PRR) was significantly different of over the three years ($P<0.01$). The highest and the lowest rates were recorded in 2001 in Barombi-Kang and in Goura, respectively (Table 2). For each year, the pod rot incidence (PRR) was significantly different between sites ($P<0.05$); Goura was significantly less attacked by pot rot disease than the others sites.

Temporal analysis

The results of simple auto-correlation of rainfall at the three sites during the three years are shown in Table 3. The correlations were very low ($P>0.05$). This is characteristic of a white noise process, meaning that the successive rainfall events were not dependant. Conversely, observations of the data presented in Table 4 (auto-correlations of PRR) showed that the successive pot rot rate were dependant, with a significant autocorrelation ($P<0.05$). Overall the values of autocorrelation decreased progressively when the lag increased. So, there was a null risk to reject wrongly the hypothesis of nullity of ρ_k coefficients; this indicates that the series is not a white noise process, with dependence between successive pod rot rates.

The cross-correlation method allowed for identification of important environmental variables (and associated lags) that affect *PRR*. Figures 4 to 6 represent cross-correlations coefficients between PRR and the rainfall. During rain, the disease did not produce symptoms immediately. Overall, the highest significant correlations were obtained with a week lag time ($P<0.05$). This result suggests a latent period of one week for the expression of the disease. Cross-correlations results of year 2001 in Goura were not presented, because of the low level of Phytophthora pod rot at the experimental plantation observed during this season.

Relationship between environmental variables and incidence of the disease

The best results determined by model selection (R^2) were obtained with the step-by-step method. Among all the environmental variables, only *RAIN* (with one week lag) contributed significantly to the PRR incidence. Table 4 presents the results of regressions that described PRR incidence as a function of quantity of rainfall per site and per year and subsequently per site using the pooled data from the three years. In Goura, only data from 1999 and 2000 were pooled, as pod rot rate was almost zero in 2001. These results always showed that quantity of rainfall had a highly significant effect on PRR incidence. However, the coefficients of determination (R^2), representing the percentage of variability explained by the model, were relatively low for the analysis done per year and per site. The R^2 were improved when the data of different years were pooled for each site.

From equations presented in Table 5, the quantity of rainfall can be used to predict PRR incidence at a cocoa farm. For example, it was observed that to reach a weekly pod rot rate of 1%, more rainfall was needed in Mbankomo (48 mm) than in Goura (39 mm) (Table 6).

Discussion

One of the objectives of this study was to establish the relationships between Phytophthora pod rot and two environmental factors. The results clearly showed that disease increased with increasing quantity of rainfall . The highest PRR incidence occurred in 2003 at the Barombi-Kang (70.3%) and Mbankomo (64.76%) sites when quantity of rainfall was very high (> 2200 mm). In contrast, the lowest losses were obtained in Goura in 2001 (1.15%) when rainfall was low (751 mm). However, in this case, the production of healthy pods per tree was also low, probably meaning that the rainfall was not sufficient to induce good fructification. It is generally indicated that a minimum of 1000 – 1200 mm of rainfall is required in a cocoa plantation to get a good yield (Mossu, 1990). The best cacao yield is obtained with an intermediate rainfall regime (1100 – 2000mm).

To better understand the effects of environmental conditions on disease development, two types of analyses were done: cross-correlation analysis and multiple regression analysis. Results of the cross-correlation analysis showed that there was a lag of one or two weeks between rainfall and disease expression. This may be the result of a incubation period, which is the period from fruit infection and the first disease symptoms. In the case of *Phytophthora megakarya*, this period lasts six days in cocoa trees (Ward et al., 1981). From the multiple regression analysis, it was possible to determine that the rainfall regime was the best indicator of PRR incidence which allows to better disease prediction. Among the different sites, mean temperature variations, which were relatively constant over the year did not influence the development of the epidemic.

These results are in agreement with those reported by Ward et al. (1981). These authors attempted to model disease development in the field by taking into account the change in the number of total pods per tree over time, the latency period (p) and the duration of active sporulation zone on each fruit (i). Considering (p)=6 days and (i)=15 days, the authors discovered that disease incidence on day (d) was correlated to the cumulative number of healthy pods on day (d), to rainfall on day (d-3) and to the cumulative duration of sporulation on pod on day (d-5).

The long term objective of this study was to contribute to the elaboration of disease forecasting models for cocoa. For this pupose we need to apprehend a great environmental variation and it will be then necessary to collect data over many years

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Table 1: Mean temperatures and rainfall in each site (April – November 1999, 2000, 2001)

Sites	Year	Surrounding temperature (°C)			Under cocoa trees temperature (°C)			Rainfall (mm)
		SMinT	SMaxT	SMeanT	UCMinT	UCMaxT	UCMeanT	
	1999	† 19.44 ± 0.18*a*	22.10 ± 0.23*b*	20.77 ± 0.20*ab*	18.21± 0.18*a*	21.16 ± 0.16*a*	19.69 ± 0.17*a*	1762 ± 15.02 *b*
Mbanko-	**2000**	19.24 ± 0.23*a*	23.78 ± 0.29*a*	21.51 ± 0.21*a*	18.54 ±0.11*a*	20.95 ± 0.27*ab*	19.74 ± 0.21*a*	1823 ± 42.45*b*
mo	**2001**	18.35 ± 0.11*b*	21.67 ± 0.34 *b*	20.01 ± 0.18 *b*	17.29 ±0.29*b*	20.23 ± 0.28*b*	18.77 ± 0.20*b*	2288 ± 13.5*a*
	1999	21.16 ± 0.13*b*	31.93 ± 0.23 *b*	26.54± 0.14*b*	20.08 ± 0.13*a*	28.25 ± 0.25*b*	24.16 ± 0.15*a*	1600 ± 8.62*a*
Goura	**2000**	21.88 ± 0.15*ab*	31.86 ± 0.16*b*	26.87± 1.02*b*	20.03 ± 0.25*a*	30.24 ± 0.14*a*	25.14± 0.16*a*	1139 ± 1.50*b*
	2001	22.59 ± 0.11*a*	34.59 ± 0.48*a*	28.59± 0.23*a*	21.02 ± 0.12*a*	27.79 ± 0.24b	24.40± 0.17*a*	751 ± 3.87*c*
Barombi	**1999**	22.67 ±0.11*a*	23.61± 0.20*a*	23.14± 0.12*a*	21.65± 0.09*a*	22.09± 0.20*a*	21.87± 0.11*a*	2003 ± 13.80*b*
-	**2000**	22.49 ±0.14*a*	23.54± 0.12*a*	23.02± 0.12*a*	20.64± 0.10*a*	22.51± 0.27*a*	21.56± 0.14*a*	1960 ± 11.83*b*
Kang	**2001**	22.11 ±0.11*a*	23.76± 0.11*a*	22.94± 0.09*a*	20.83± 0.11*a*	22.75± 0.28*a*	21.79± 0.18*a*	2873 ± 9.29*a*

† *Values are means ± standard error*

For each variable at a given site, values followed by the same letter are not significantly different with Newman-Keuls test at 5% level

Table 2: Mean pod rot rate and production in each site (April – November 1999, 2000, 2001)

Sites	Year	Final pod rot rate (%)	Number of healthy pods per tree
Mbankomo	**1999**	† 44.26 ± 3.70*c* §	10.62 ±1.04*a*
	2000	59.43 ± 3.52*b*	7.71 ± 0.71*b*
	2001	64.76 ± 4.93*a*	11.14 ±0.97*a*
Goura	**1999**	16.61 ± 1.56*a*	10.87 ± 1.08*c*
	2000	13.04 ± 1.42*a*	21.31 ± 2.17*a*
	2001	1.15 ± 0.23*b*	13.85 ± 0.89*b*
Barombi-Kang	**1999**	41.89 ± 1.77*b*	21.90 ± 0.44*a*
	2000	35.19 ± 1.18*c*	19.00 ± 0.38*b*
	2001	70.31 ± 2.89*a*	6.50 ± 0.76*c*

† *Means are values ± standard error*

§ *For each variable at a given site, values followed by the same letter are not significantly different with Newman-Keuls test at 5% level*

Table 3: Auto-correlations of rainfall at different sites (1999 – 2001)

Site	Year	Lag (week)	Correlation	White noise † (P value)
Mbankomo	1999	1	0.07769	0.5880
		2	0.03813	
		3	0.27777	
		4	0.18834	
	2000	1	-0.03364	0.2403
		2	-0.12438	
		3	-0.17005	
		4	0.31207	
	2001	1	0.33633	0.4040
		2	0.20602	
		3	0.06774	
		4	0.10049	
Goura	1999	1	0.04657	0.8672
		2	-0.02783	
		3	0.14162	
		4	0.20364	
	2000	1	0.01838	0.9663
		2	-0.01026	
		3	0.07725	
		4	-0.02992	
	2001	1	0.36892	0.5298
		2	0.12501	

		3	0.03107	
		4	-0.04581	
Barombi-Kang	1999	1	-0.00288	0.6686
		2	-0.26238	
		3	-0.04436	
		4	-0.02525	
	2000	1	-0.00820	0.9907
		2	0.03259	
		3	-0.05487	
		4	-0.11992	
	2001	1	-0.00529	0.8724
		2	0.13300	
		3	0.06208	
		4	-0.19185	

† White noise (P value): non significance of the correlation if P-Value>0.05

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1 **Table 4: Auto-correlations of pod rot rate at different sites (1999 – 2001)**

Site	Year	Lag (week)	Correlation	White noise (P value)
Mbankomo	1999	1	0.38177	0.0007
		2	0.39539	
		3	0.49067	
		4	0.24886	
	2000	1	0.81794	<0.0001
		2	0.68899	
		3	0.51443	
		4	0.35122	
	2001	1	0.69931	<0.0001
		2	0.33266	
		3	0.14526	
		4	-0.07983	
Goura	1999	1	0.73008	<0.0001
		2	0.52308	
		3	0.32898	
		4	0.20190	
	2000	1	0.45732	0.0052
		2	0.48730	
		3	0.34699	
		4	0.02463	
	2001	1	0.39230	0.0174
		2	0.08095	

		3	-0.31991	
		4	-0.26096	
Barombi-Kang	1999	1	0.61937	0.0005
		2	0.45014	
		3	0.23869	
		4	0.16833	
	2000	1	0.63346	<0.0001
		2	0.57992	
		3	0.50878	
		4	0.15422	
	2001	1	0.86274	<0.0001
		2	0.70645	
		3	0.52839	
		4	0.27160	

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Table 5: Regression models between pod rot rate and rainfall regime.

Site	**Year**	**Equation of the model***	**R^2**	**P-value**
Mbankomo	1999	† $y = 0.168\ RAIN$	53 %	< 0.001
	2000	$y = 0.096\ RAIN$	56 %	< 0.001
	2001	$y = 0.146\ RAIN$	61%	< 0.001
	1999 - 2001	$y = 0.120\ RAIN$	69 %	< 0.001
Goura	1999	$y = 0.150\ RAIN$	62 %	< 0.001
	2000	$y = 0.167\ RAIN$	57 %	< 0.001
	1999 - 2000	$y = 0.\ 146\ RAIN$	74 %	< 0.001
Barombi-Kang	1999	$y = 0.\ 429\ RAIN$	68 %	< 0.001
	2000	$y = 0.\ 210\ RAIN$	54 %	< 0.001
	2001	$y = 0.\ 223\ RAIN$	58 %	< 0.001
	1999 -2001	$y = 0.\ 257\ RAIN$	81 %	< 0.001

† $y = arcsine\sqrt{PRR}$, with *PRR*= Pod Rot Rate, *RAIN*=Rainfall)

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Table 6: Rainfall (mm) necessary to start a weekly pod rot rate of 1% per year in different sites (estimations based on the equations of Table 4)

Sites	Year			
	1999	2000	2001	1999-2001 (mean)
Mbankomo	34.2	59.8	39.3	47.8
Goura	38.3	34 .4	-	39.3
Barombi-Kang	13.8	27 .3	25.7	22.3

Figures Please read the guidelines for ms submission.

1. remove the external boxes
2. Close the graph boxes
3. Put legend within the graph boses
4. Combine graphs within figures, graph with the same ‘X’ axix should combine to save space and to provide more visibility to the data.
5. Put the figure captions on a separate pages before the presentation of figures

Figure captions

Figure 1: Evolution of weekly pod rot rate and of daily rainfall at Mbankomo

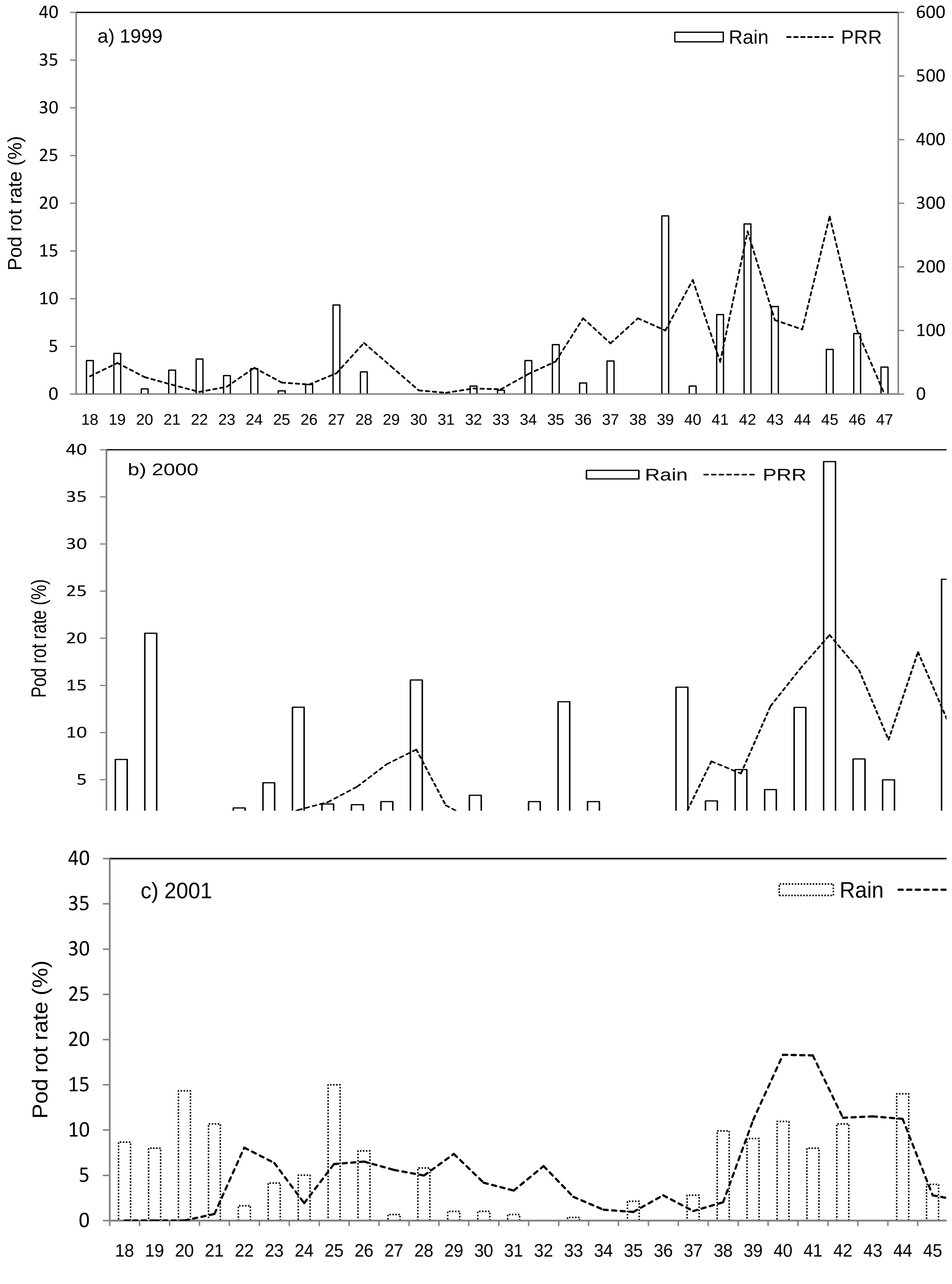
Figure2: Evolution of weekly pod rot rate and of daily rainfall at Goura

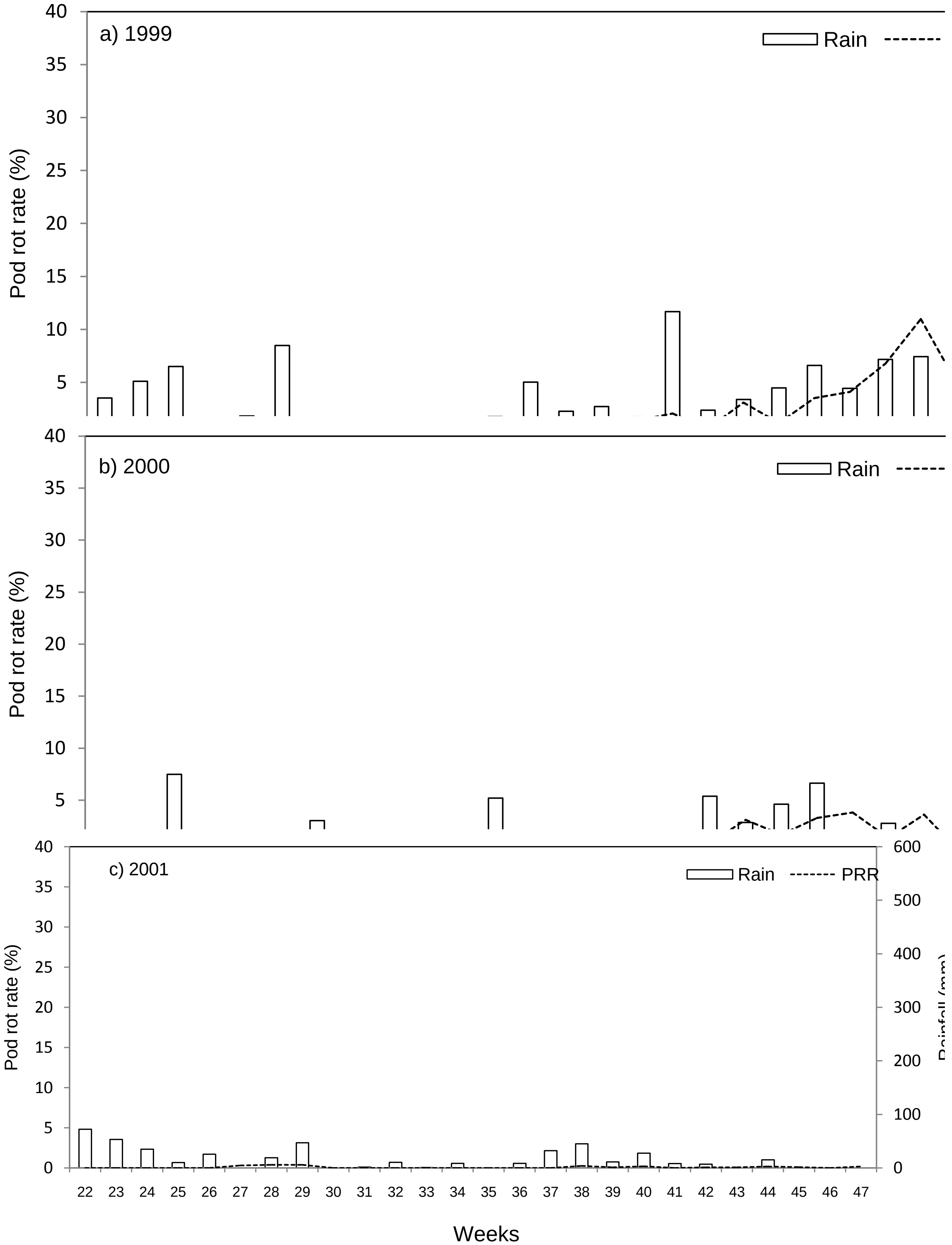
Figure3: Evolution of weekly pod rot rate and of daily rainfall at Barombi-Kang

Figure 4: Cross correlations coefficients of Pod Rot Rate (PRR) – Rainfall, for several lags (in week), at Mbankomo

Figure 5: Cross correlations coefficients of Pod Rot Rate (PRR) – Rainfall, for several lags (in week), at Goura

Figure 6: Cross correlations coefficients of Pod Rot Rate (PRR) – Rainfall, for several lags (in week) at Barombi-Kang


a) 1999
Rain
PRR
Pod rot rate (%)
b) 2000
Rain
PRR
Pod rot rate (%)
c) 2001
Rain
Pod rot rate (%)


a) 1999
Rain
b) 2000
Rain
c) 2001
Rain
PRR
Pod rot rate (%)
Pod rot rate (%)
Pod rot rate (%)
40
35
30
25
20
15
10
5
0
600
500
400
300
200
100
22
23
24
25
26
27
28
29
30
31
32
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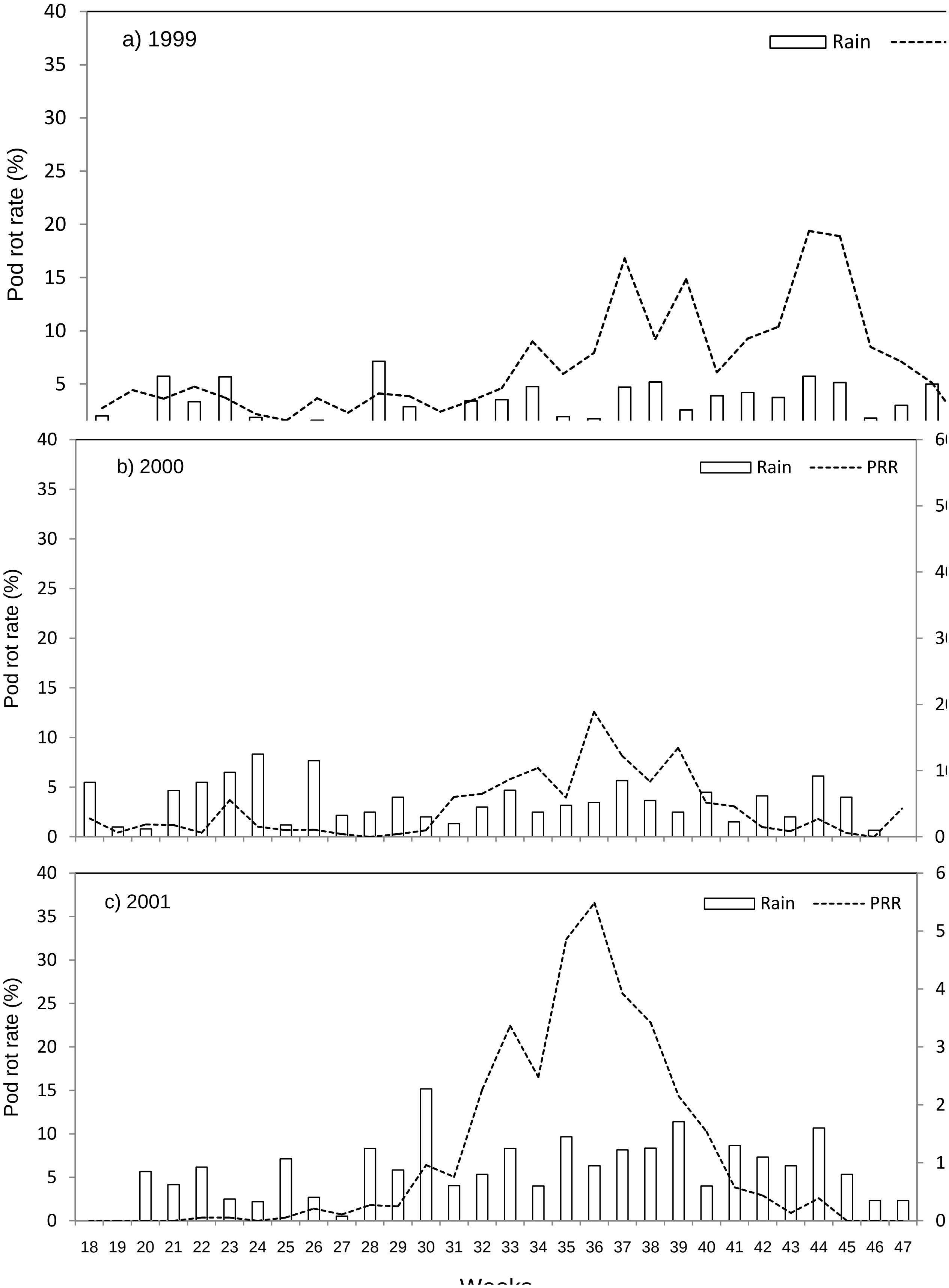
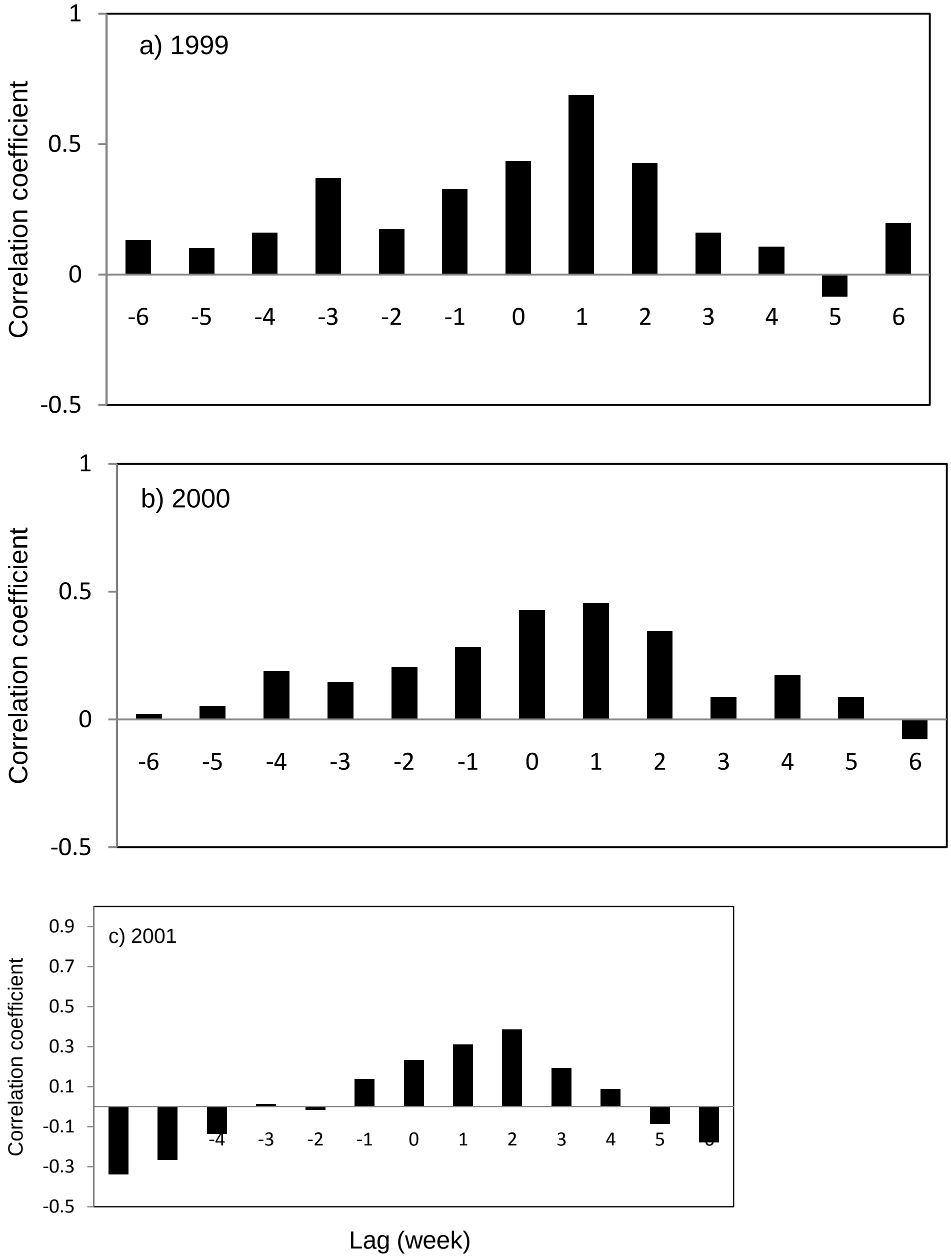
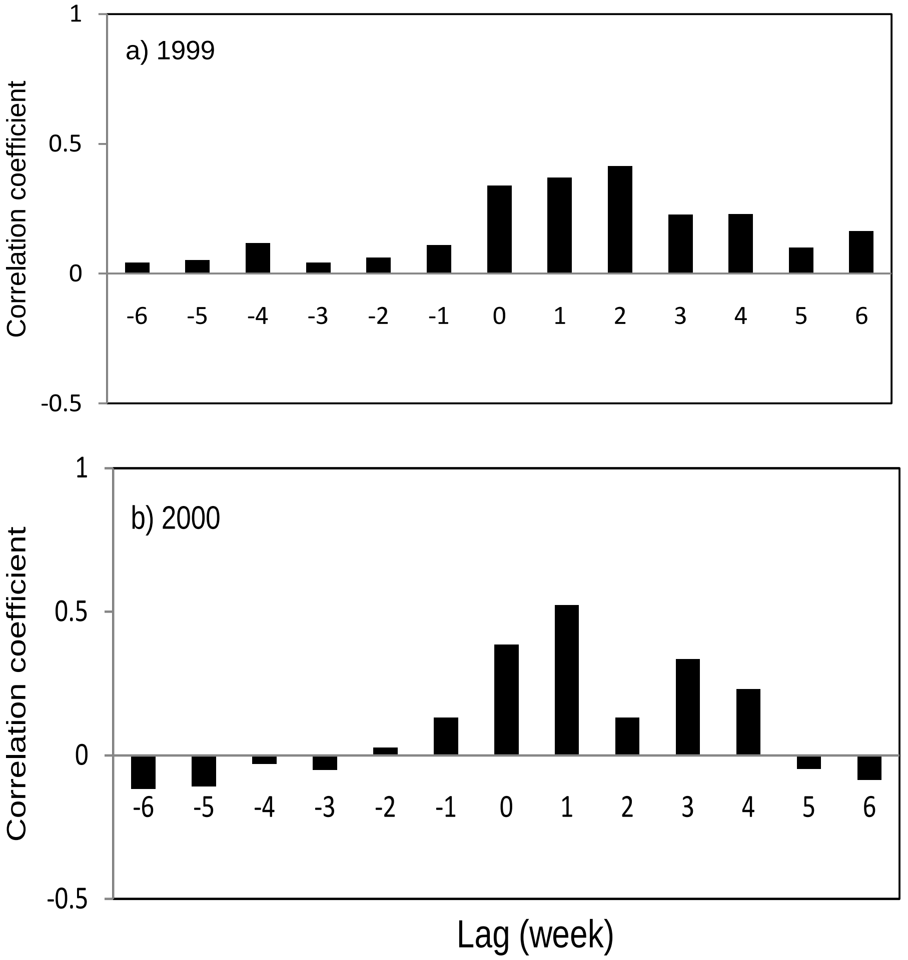
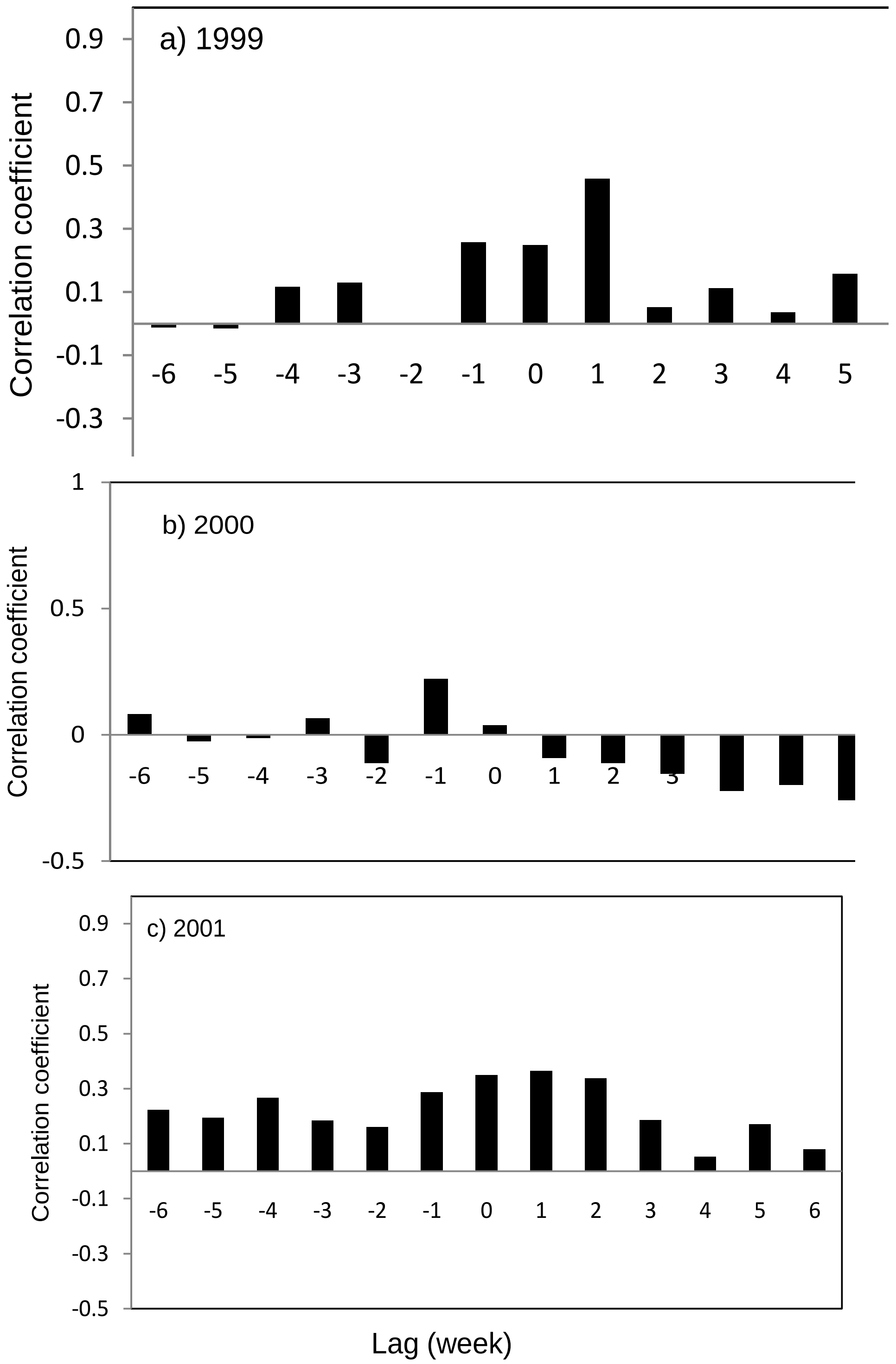
34
35
36
37
38
39
40
41
42
43
44
45
46
47
Weeks


a) 1999
Rain
Pod rot rate (%)
40
35
30
25
20
15
10
5
b) 2000
Rain
PRR
Pod rot rate (%)
0
c) 2001
Rain
PRR
Pod rot rate (%)
6
5
4
3
2
1
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47


a) 1999
b) 2000
c) 2001
Correlation coefficient
Lag (week)
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
1
0.5
0
-0.5
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5


a) 1999
b) 2000
Correlation coefficient
1
0.5
0
-0.5
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Lag (week)


a) 1999
Correlation coefficient
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5
b) 2000
Correlation coefficient
1
0.5
0
-0.5
-6 -5 -4 -3 -2 -1 0 1 2 3
c) 2001
Correlation coefficient
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Lag (week)