

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

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1

2 **Relationships between cocoa *Phytophthora* pot rot disease and climatic**

3 **variables in Cameroon**

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10

11

12 **Relations entre l'incidence de la pourriture des cabosses due à *Phytophthora***

13 **et plusieurs variables climatiques au Cameroun**

14

15

1 **Abstract**

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

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

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

21

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

24

1 **Résumé**

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

10 Cette étude a été conduite dans trois sites du Cameroun (Mbankomo, Goura et Barombi-
11 Kang); cent arbres ont été observés par site. Les données concernant la maladie et la
12 production ont été collectées chaque semaine, alors que les variables climatiques ont été
13 collectées tous les jours. Les données ont été recueillies durant trois années consécutives
14 (1999-2001). Des autocorrélations, des corrélations croisées et des régressions multiples ont
15 été utilisées pour mieux comprendre les relations entre l'incidence de la maladie et les
16 facteurs climatiques.

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

22

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

25

1 **Introduction**

2

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

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

17 The present study focuses on the incidence of environmental factors on dynamics of the disease.
18 Whether in Cote d’Ivoire (Tarjot, 1964, 1967), Ghana (Asare-Nyako, 1973), Cameroon (Muller,
19 1974a, 1974b), Jamaica (Henry, 1977) or Nigeria (Gregory and Maddison, 1981),
20 epidemiological observations showed that *Phytophthora* pod rot appears when there is a
21 conjunction between the presence of fruit on trees, whatever their growth stage, on one hand and
22 rainy season on the other hand. The effects of climate on the epidemic process are only known in
23 a macroscopic approach in cocoa producing zones (Tarjot, 1964). In Cameroon for example, the
24 incidence of disease tends to be higher in some agro-ecological zones with a mono-modal
25 rainfall regime, compared to those with a bi-modal rainfall regime (Ndoumbè-Nkeng, 2002).

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

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

13

14 **Materials and Methods**

15

16 **Study sites and experimental design**

17

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

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

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

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

12 At each of the three plots, 100 trees were randomly distributed. The plot was surrounded with
13 a phytosanitary barrier made up of two rows of cocoa trees, to prevent chemical treatments
14 and pathogen spread from neighbouring farms. For the purpose of field observations, the
15 observed trees were divided into three levels: 0–0.5 m (level 1), 0.5–1.50 m (level 2) and >
16 1.50 m (level 3). Inside the same plantation, the spacing among trees varied from 2.5 x 2.5 m
17 to 3 x 3m, corresponding to tree densities of 1111 to 1600 cocoa trees ha⁻¹.

18

19 **Data collection**

20

21 Rotten pods (caused by *Phytophthora* sp., *ROT*), wilted fruit (early desiccation, *WILT*), fruit
22 damaged by rodents (*DAM*), fruit infected by diseases other than *Phytophthora* pod rot (*OD*),
23 cherelles (fruit \leq 4 cm length, *CHER*), young pods (fruit > 4 cm length but not yet at adult
24 stage, *YP*), adult pods (but not yet mature, *AP*), and healthy mature pods (*MP*) were counted

1 weekly. These variables were chosen for weekly estimation of pod rot rate (Number of rotten
2 pods / Number of all the pods).

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

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

12

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

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

18

19

$$PRR_i = \frac{ROT_i}{(ROT_i + MP_i)} * 100$$

20

21 where PRR_i = Pod rot rate at the week i

22 ROT_i = number of rotten pods at the week i

23 MP_i = number of mature pods at the week i

24

25 The minimum surrounding temperatures (*SMinT*) and those under the cocoa trees canopy
26 (*UCMinT*), and the maximal ones (*SMaxT*, *UCMaxT*), expressed in degrees Celsius, represent

1 respectively, the averages of minimal and maximal temperatures of the week (7 days). The
2 mean temperatures (*SMeanT*, *UCMeanT*) are the averages of both weekly minimum and
3 maximum temperatures. The daily thermal amplitude (*Amp*) was calculated, by taking the
4 difference between maximum and minimum daily temperatures.

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

7

8 **Statistical analyses**

9

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

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

16

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

1 The autocorrelation coefficient ρ , of lag (or *period*) k was calculated, considering the $T-1$
 2 pairs of observations $(y_1, y_2), (y_2, y_3), \dots, (y_{T-1}, y_T)$, in the following manner (Box and Jenkins,
 3 1976 ; Tomassone et *al.*, 1993 ; Bourbonnais, 2000) :

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

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

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

10

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

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

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

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

4

5 **Results**

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

9

10 *Temperature and rainfall*

11

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

25

1 ***Production and Phytophthora pod rot rate***

2

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

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

12

13 **Temporal analysis**

14

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

23

24 The cross-correlation method allowed for identification of important environmental variables
25 (and associated lags) that affect *PRR*. Figures 4 to 6 represent cross-correlations coefficients

1 between PRR and the rainfall. During rain, the disease did not produce symptoms
2 immediately. Overall, the highest significant correlations were obtained with a week lag time
3 ($P < 0.05$). This result suggests a latent period of one week for the expression of the disease.
4 Cross-correlations results of year 2001 in Goura were not presented, because of the low level
5 of *Phytophthora* pod rot at the experimental plantation observed during this season.

7 **Relationship between environmental variables and incidence of the disease**

8
9 The best results determined by model selection (R^2) were obtained with the step-by-step
10 method. Among all the environmental variables, only *RAIN* (with one week lag) contributed
11 significantly to the PRR incidence. Table 4 presents the results of regressions that described
12 PRR incidence as a function of quantity of rainfall per site and per year and subsequently per
13 site using the pooled data from the three years. In Goura, only data from 1999 and 2000 were
14 pooled, as pod rot rate was almost zero in 2001. These results always showed that quantity of
15 rainfall had a highly significant effect on PRR incidence. However, the coefficients of
16 determination (R^2), representing the percentage of variability explained by the model, were
17 relatively low for the analysis done per year and per site. The R^2 were improved when the data
18 of different years were pooled for each site.

19
20 From equations presented in Table 5, the quantity of rainfall can be used to predict PRR
21 incidence at a cocoa farm. For example, it was observed that to reach a weekly pod rot rate of
22 1%, more rainfall was needed in Mbankomo (48 mm) than in Goura (39 mm) (Table 6).

24 **Discussion**

25

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

11

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

22

23 These results are in agreement with those reported by Ward et al. (1981). These authors
24 attempted to model disease development in the field by taking into account the change in the
25 number of total pods per tree over time, the latency period (p) and the duration of active

1 sporulation zone on each fruit (i). Considering (p)=6 days and (i)=15 days, the authors
2 discovered that disease incidence on day (d) was correlated to the cumulative number of
3 healthy pods on day (d), to rainfall on day (d-3) and to the cumulative duration of sporulation
4 on pod on day (d-5).

5

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

9

10

11

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13

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20

21

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1 **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 ± 0.18a | 22.10 ± 0.23b | 20.77 ± 0.20ab | 18.21 ± 0.18a | 21.16 ± 0.16a | 19.69 ± 0.17a | 1762 ± 15.02 b |
| Mbanko- | 2000 | 19.24 ± 0.23a | 23.78 ± 0.29a | 21.51 ± 0.21a | 18.54 ± 0.11a | 20.95 ± 0.27ab | 19.74 ± 0.21a | 1823 ± 42.45b |
| mo | 2001 | 18.35 ± 0.11b | 21.67 ± 0.34 b | 20.01 ± 0.18 b | 17.29 ± 0.29b | 20.23 ± 0.28b | 18.77 ± 0.20b | 2288 ± 13.5a |
| | 1999 | 21.16 ± 0.13b | 31.93 ± 0.23 b | 26.54 ± 0.14b | 20.08 ± 0.13a | 28.25 ± 0.25b | 24.16 ± 0.15a | 1600 ± 8.62a |
| Goura | 2000 | 21.88 ± 0.15ab | 31.86 ± 0.16b | 26.87 ± 1.02b | 20.03 ± 0.25a | 30.24 ± 0.14a | 25.14 ± 0.16a | 1139 ± 1.50b |
| | 2001 | 22.59 ± 0.11a | 34.59 ± 0.48a | 28.59 ± 0.23a | 21.02 ± 0.12a | 27.79 ± 0.24b | 24.40 ± 0.17a | 751 ± 3.87c |
| Barombi | 1999 | 22.67 ± 0.11a | 23.61 ± 0.20a | 23.14 ± 0.12a | 21.65 ± 0.09a | 22.09 ± 0.20a | 21.87 ± 0.11a | 2003 ± 13.80b |
| - | 2000 | 22.49 ± 0.14a | 23.54 ± 0.12a | 23.02 ± 0.12a | 20.64 ± 0.10a | 22.51 ± 0.27a | 21.56 ± 0.14a | 1960 ± 11.83b |
| Kang | 2001 | 22.11 ± 0.11a | 23.76 ± 0.11a | 22.94 ± 0.09a | 20.83 ± 0.11a | 22.75 ± 0.28a | 21.79 ± 0.18a | 2873 ± 9.29a |

2 † Values are means ± standard error

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

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

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

2 † Means are values ± standard error

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

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

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

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12 Please format the tables according to the Canadian Journal of Plant Pathology

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

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

| Site | Year | Equation of the model* | R ² | P-value |
|------------------|-------------|----------------------------|----------------|---------|
| Mbankomo | 1999 | † $y = 0.168 \text{ RAIN}$ | 53 % | < 0.001 |
| | 2000 | $y = 0.096 \text{ RAIN}$ | 56 % | < 0.001 |
| | 2001 | $y = 0.146 \text{ RAIN}$ | 61% | < 0.001 |
| | 1999 - 2001 | $y = 0.120 \text{ RAIN}$ | 69 % | < 0.001 |
| Goura | 1999 | $y = 0.150 \text{ RAIN}$ | 62 % | < 0.001 |
| | 2000 | $y = 0.167 \text{ RAIN}$ | 57 % | < 0.001 |
| | 1999 - 2000 | $y = 0.146 \text{ RAIN}$ | 74 % | < 0.001 |
| Barombi- Kang | 1999 | $y = 0.429 \text{ RAIN}$ | 68 % | < 0.001 |
| | 2000 | $y = 0.210 \text{ RAIN}$ | 54 % | < 0.001 |
| | 2001 | $y = 0.223 \text{ RAIN}$ | 58 % | < 0.001 |
| | 1999 - 2001 | $y = 0.257 \text{ RAIN}$ | 81 % | < 0.001 |

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

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1 Please format the tables according to the Canadian Journal of Plant Pathology

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3 **Table 6:** Rainfall (mm) necessary to start a weekly pod rot rate of 1% per year in different
4 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 |

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1 Figures Please read the guidelines for ms submission.

2 1. remove the external boxes

3 2. Close the graph boxes

4 3. Put legend within the graph boses

5 4. Combine graphs within figures, graph with the same 'X' axix should combine to save space
6 and to provide more visibility to the data.

7 5. Put the figure captions on a separate pages before the presentation of figures

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1 **Figure captions**

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

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

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

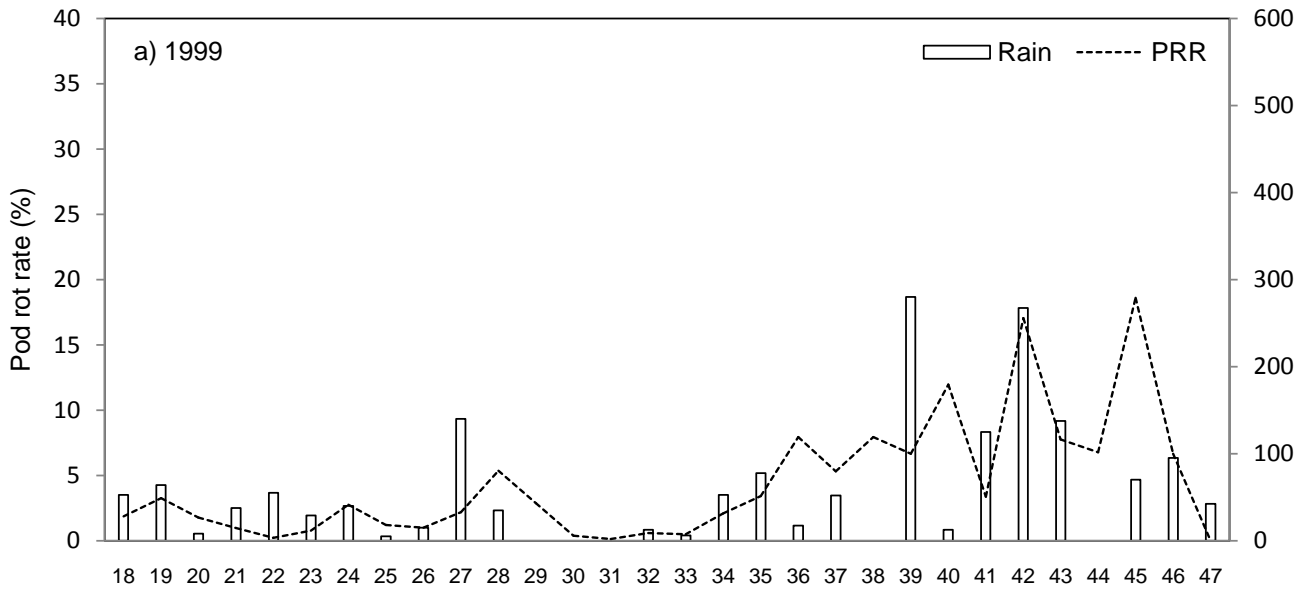
5 Figure 4: Cross correlations coefficients of Pod Rot Rate (PRR) – Rainfall, for several lags (in
6 week), at Mbankomo

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

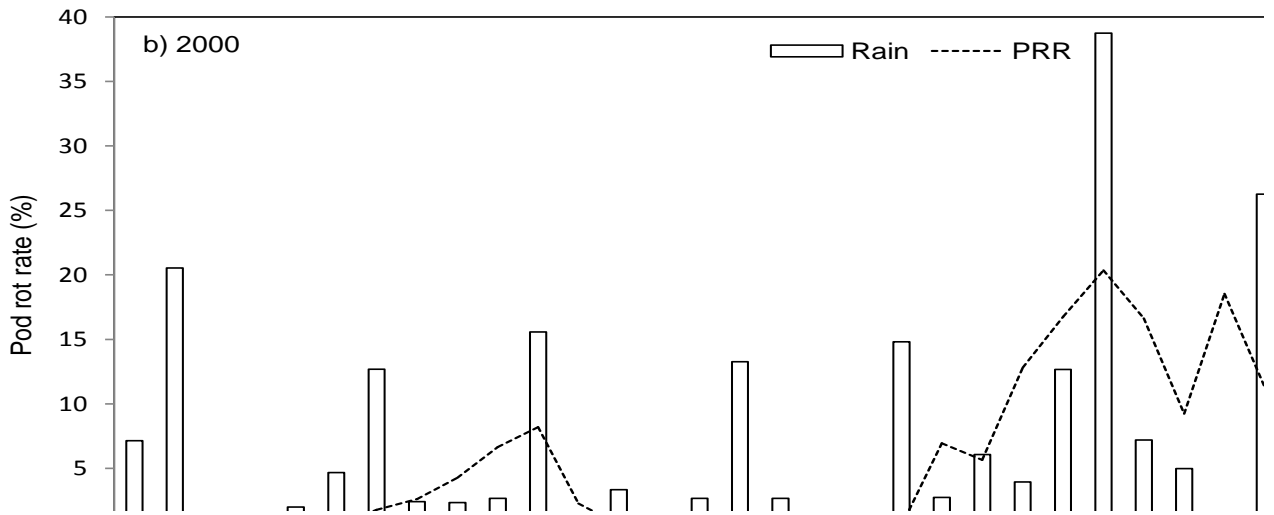
9 Figure 6: Cross correlations coefficients of Pod Rot Rate (PRR) – Rainfall, for several lags (in
10 week) at Barombi-Kang

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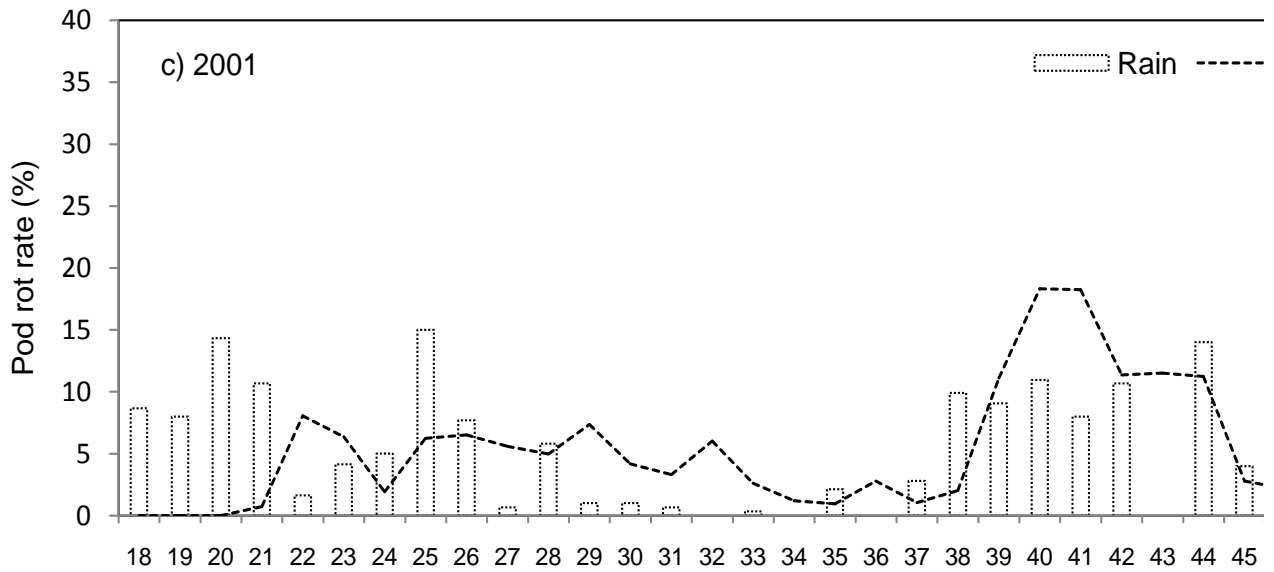
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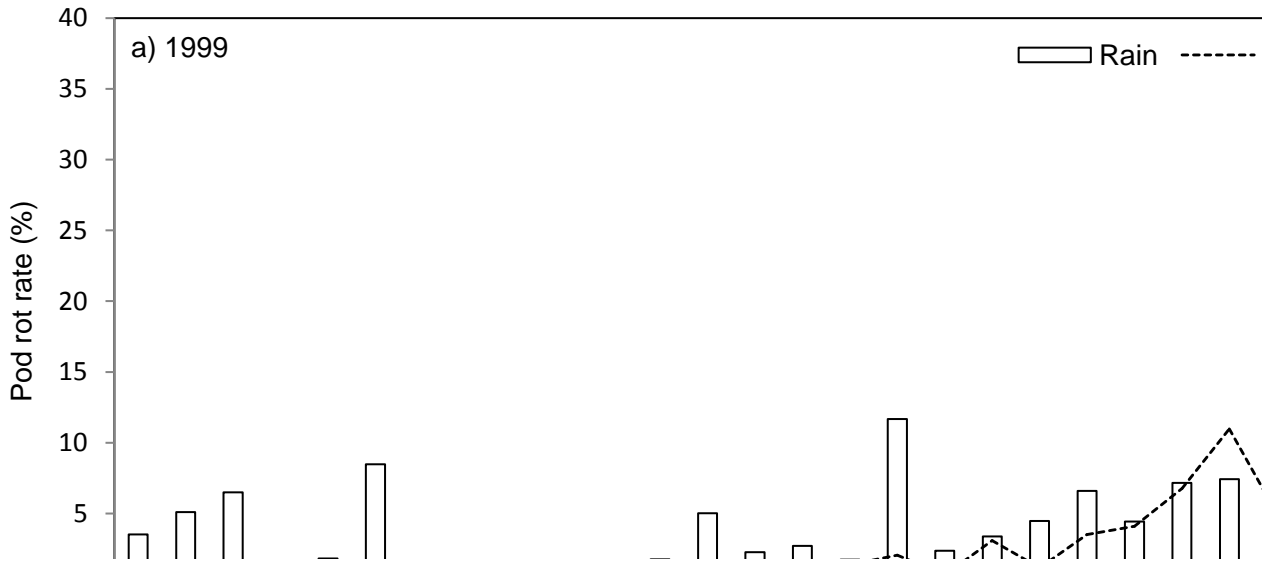


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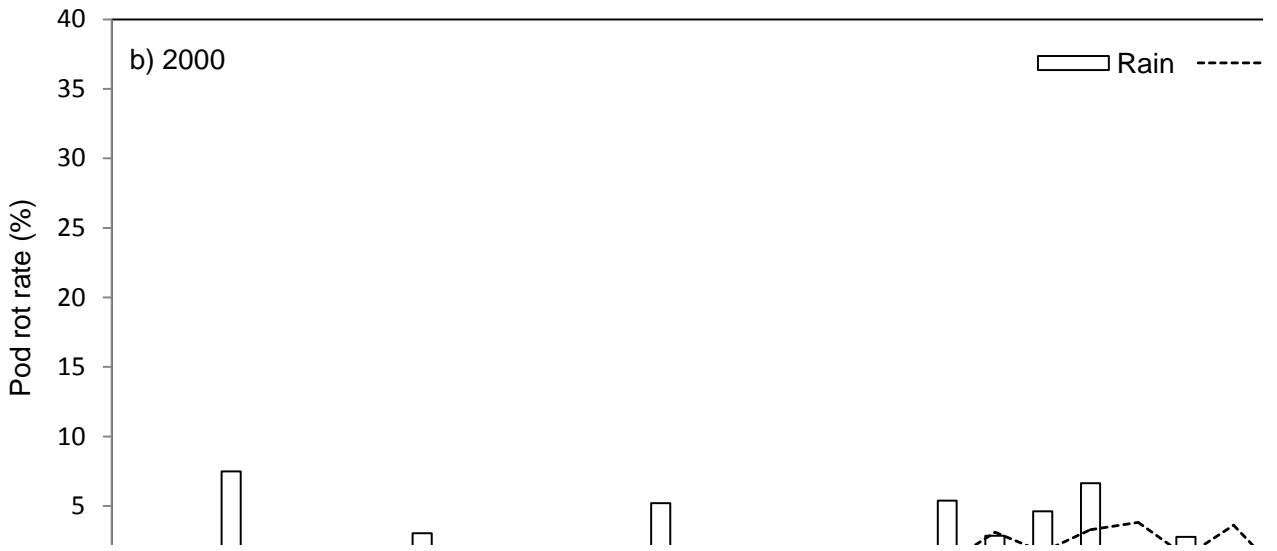


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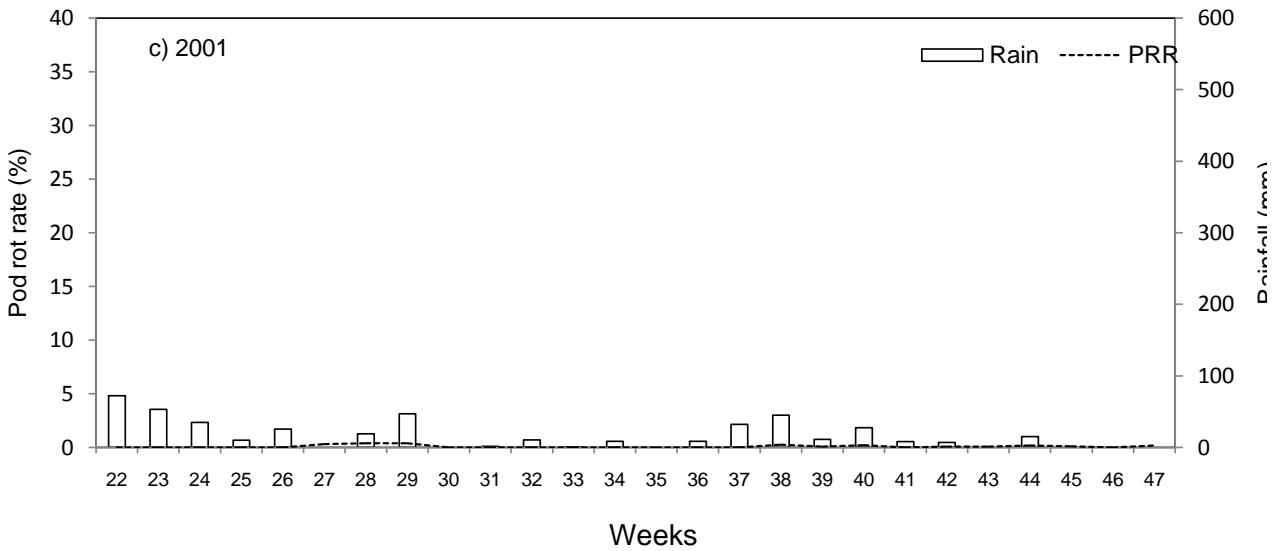
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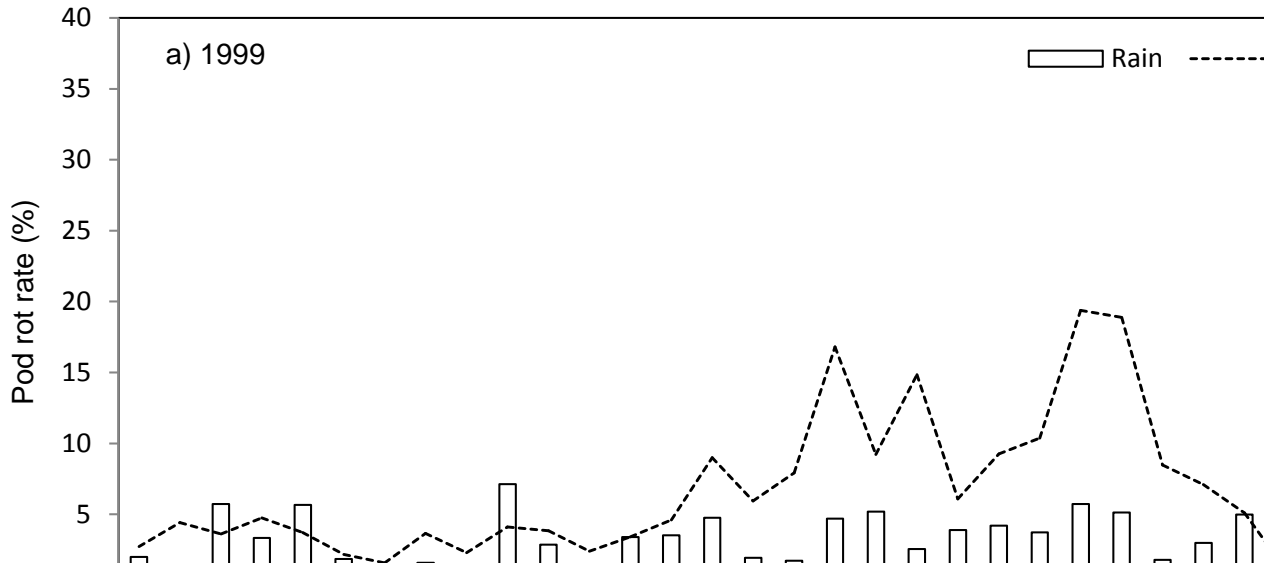


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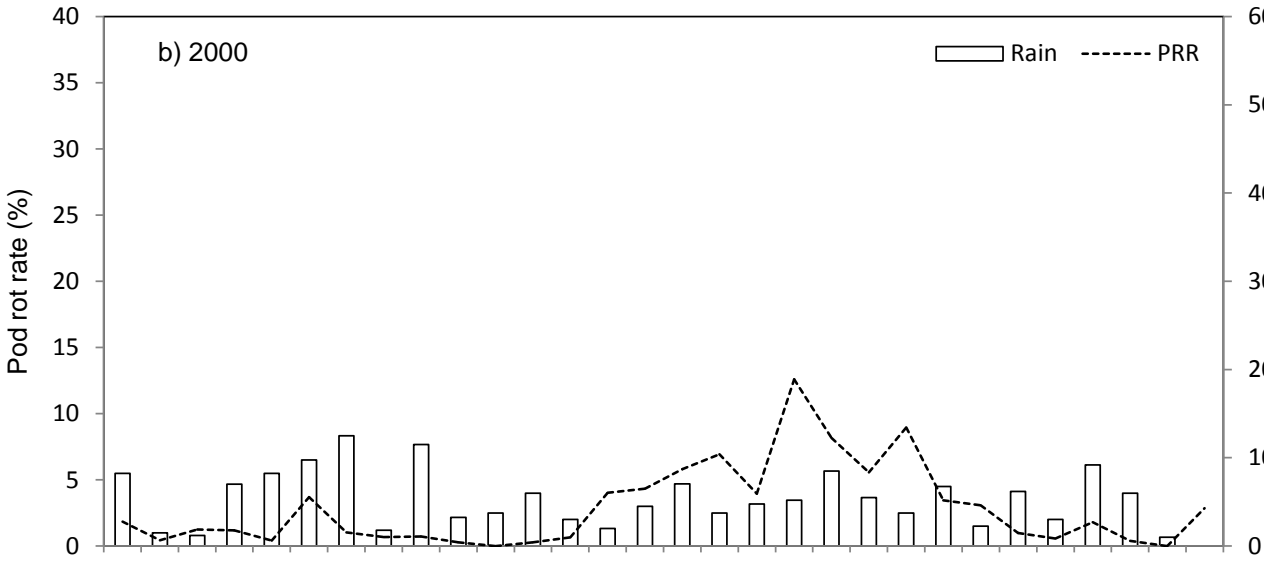
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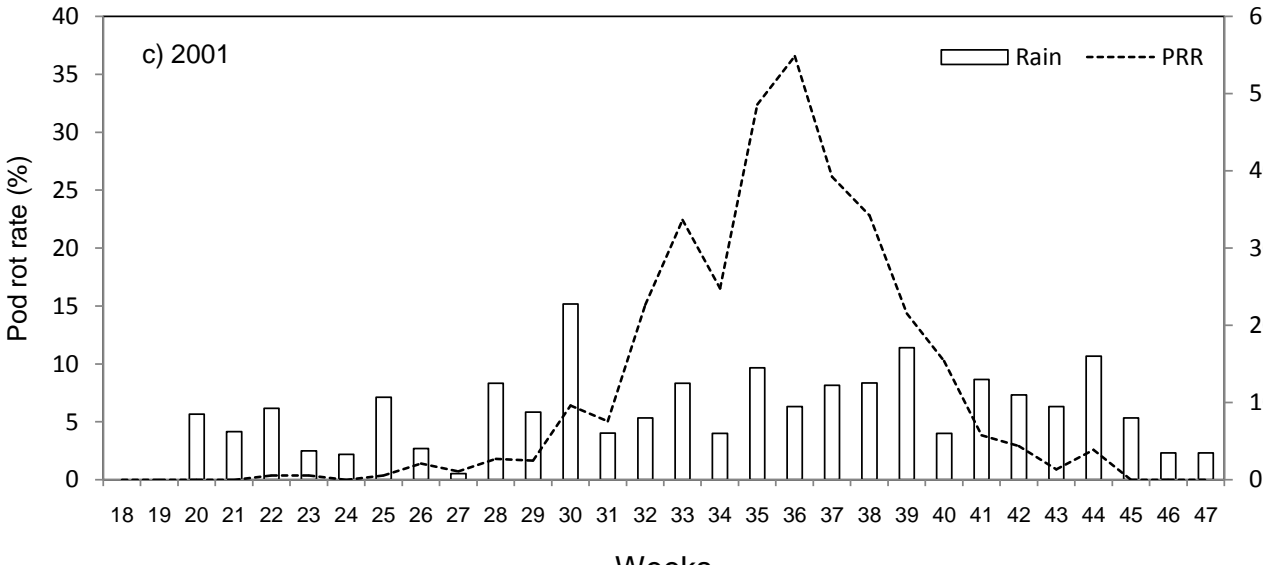
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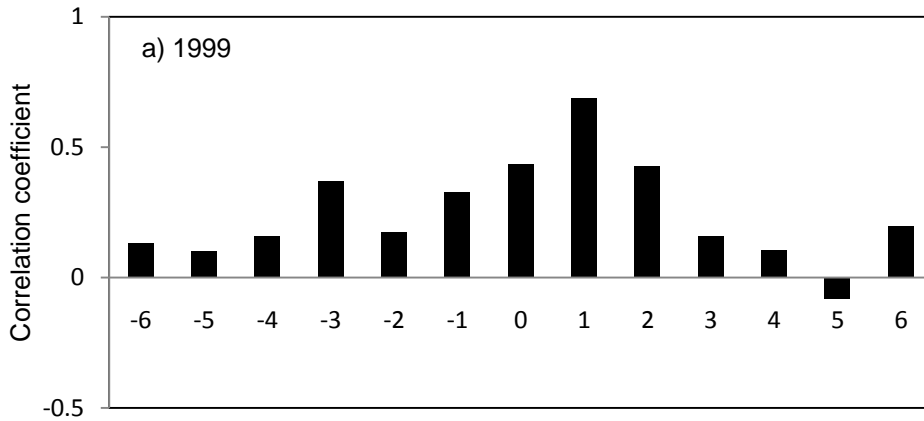
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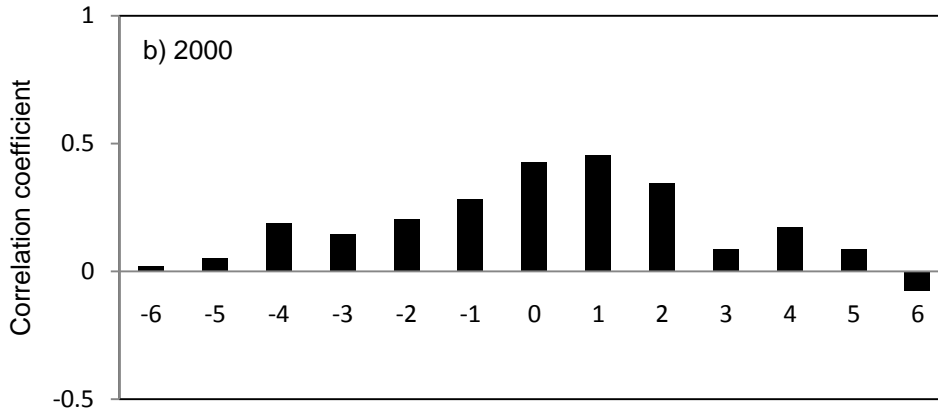
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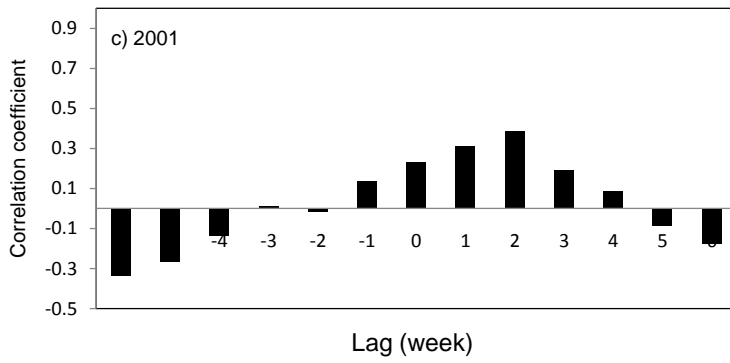
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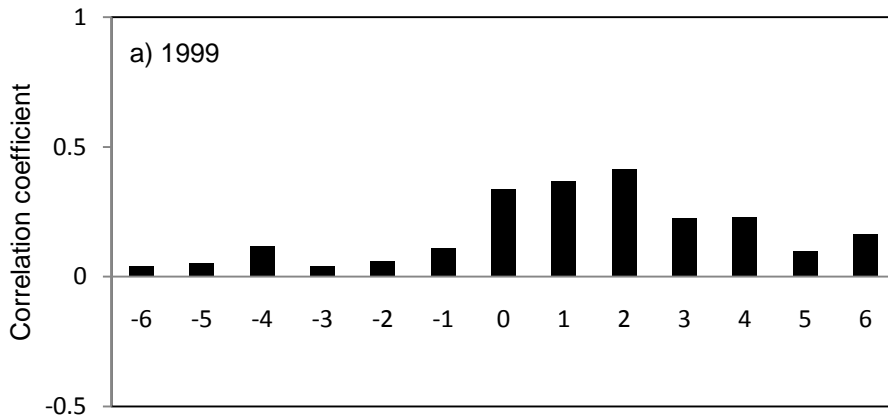
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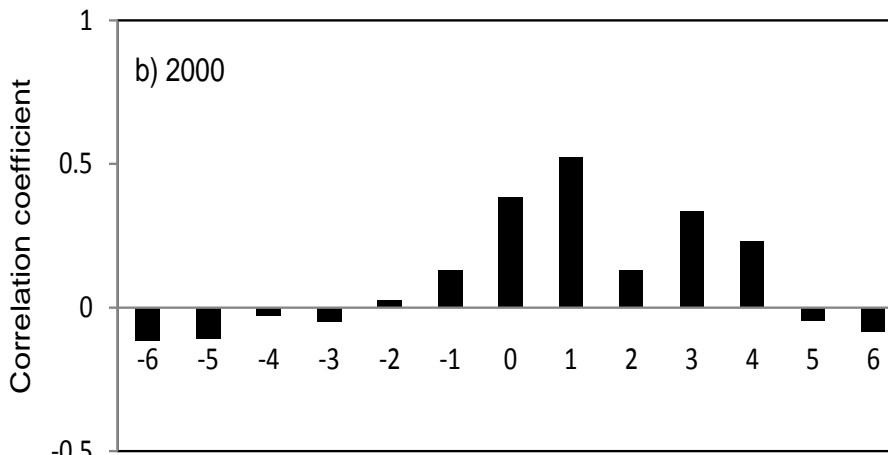
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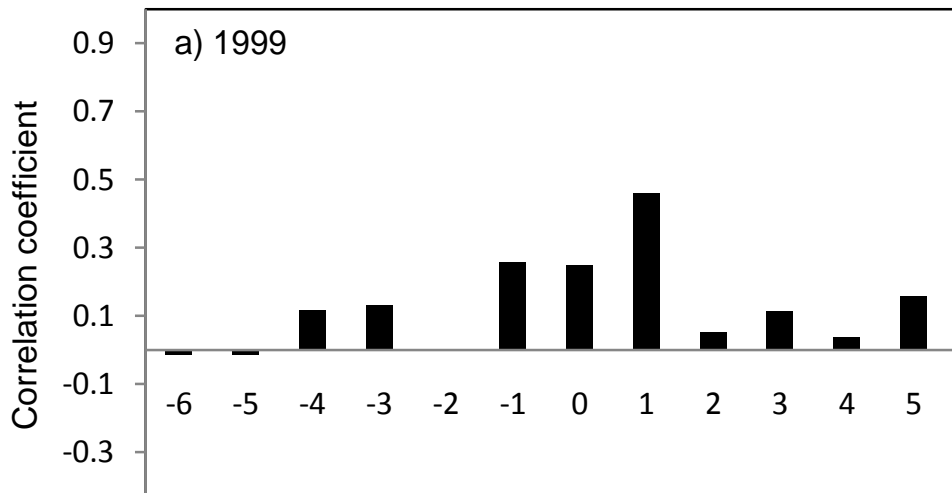


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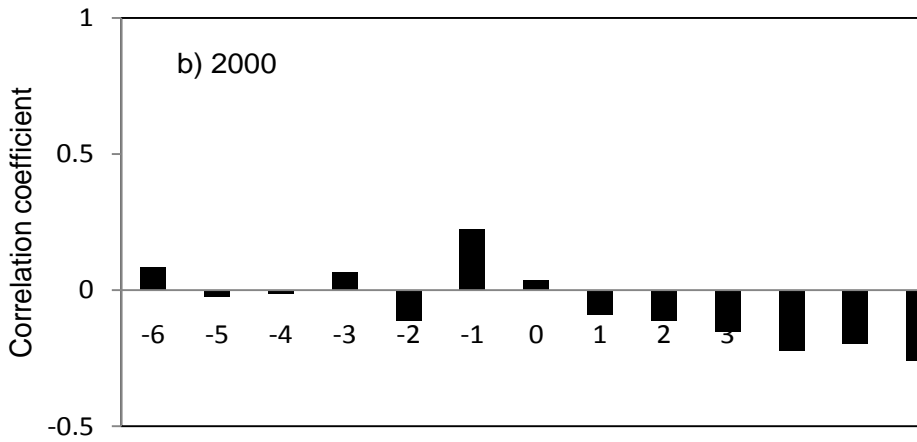


Lag (week)

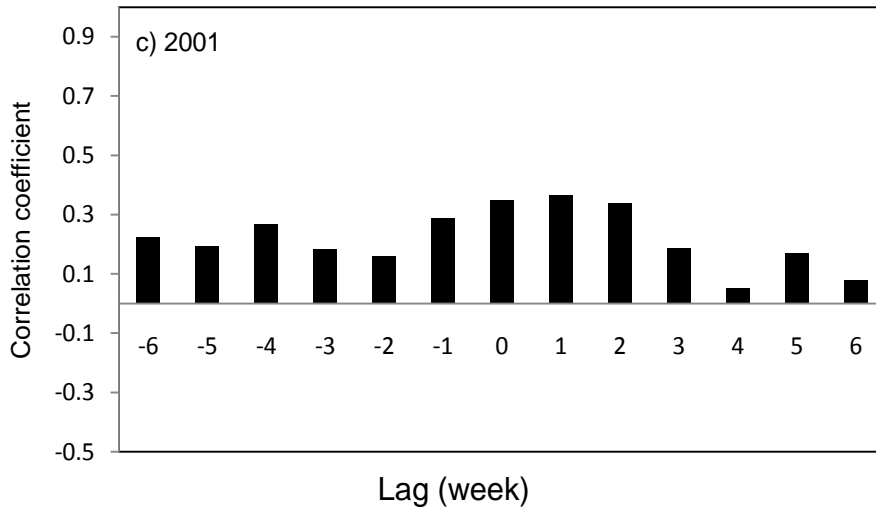
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