Australasian Plant Pathology (2019) 48:245–252
https://doi.org/10.1007/s13313-019-0623-y

ORIGINAL PAPER

Brown eye spot in coffee subjected to different drip irrigation and fertilization management

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Received: 9 April 2018 / Accepted: 29 January 2019 / Published online: 12 February 2019

Abstract

Brown eye spot is one of the main diseases of coffee trees. The aim of this study was to evaluate the severity of brown eye spot in coffee plantations subjected to different drip irrigation and fertilization management. The study was carried out in Lavras-MG, Brazil, in a plantation of the cultivar MGS Travessia. Disease assessments were performed monthly from March 2012 to June 2014. The experimental design was a randomized block design with 12 treatments. The irrigation treatments were the control without irrigation, irrigation all year, suspension of irrigation for 30 days in July, and for 70 days between July and September. Fertilization treatments were recommended rate of NK fertilizer, high rate of NK plus P and high rate of NK. severity of the disease integrated into area under the disease progress curve (AUDPC). There was a difference in AUDPC in the evaluated years, reflecting the biennial characteristic of the coffee crop. There was no significant interaction between irrigation and fertilization. However, when irrigation and fertilization treatments where analyzed separately, the suspension of irrigation for 70 days between July and September in 2012 favored brown eye spot and in the same year the high rates of NK increased productivity.

Keywords *Cercospora coffeicola* · Brown eye spot · Irrigated coffee growing · Phosphate fertilization · *Coffea arabica*

Introduction

The poor distribution of rainfall has been frequent in areas suitable for planting coffee, such as in the southern state of Minas Gerais, the largest Arabica coffee producing region in Brazil, with an estimated area of 484,000 ha and production of 13.26 million 60-kg bags of green coffee (Conab 2017). In dry situations, plants absorb less nutrients, compromising the formation and maintenance of resistance barriers to plant pathogens. Thus, there may be a higher intensity of diseases in the field (Marschner 2012). Among these diseases, we can mention brown eye spot (*Cercospora coffeicola*), which has been disseminated in all coffee producing regions of Brazil and is influenced by nutritional imbalances (Garcia Junior et al. 2003; Pozza et al. 2000, 2001). It is responsible for defoliation, reduction in development, and productivity loss (Pozza et al. 2010), besides reducing the quality of grains and beverage (Lima et al. 2012).

In these regions, irrigation has become economically viable and has been used to meet the need of water for coffee plantation at specific times (Lima et al. 2008; Coelho et al. 2009). The water availability makes nutrients available for absorption. Once in the plant, it may constitute the first resistance barriers, such as the wax layer and the cell wall, hindering penetration and colonization by pathogens (Pozza and Pozza 2012).

In drip-irrigated systems, the water is distributed in a localized way and it is possible to split the fertilization by fertigation, reducing the application costs of these products, avoiding imbalances by applying high doses and loss by leaching. Furthermore, this method does not modify the microclimate of the plant, reducing the severity of diseases (Talamini et al. 2003; Miranda et al. 2006). Among the

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nutrients capable of being distributed and absorbed, phosphorus is mentioned. For many years, coffee was considered a plant unable to respond to phosphate fertilization in its production phase, but some authors observed its influence during this stage of the plant (Scalco et al. 2011; Reis et al. 2011, 2013). Phosphorus performs structural, physiological and biochemical functions essential to the plant and is part of its energy molecule, ATP (adenosine triphosphate) (Lehninger et al. 2014). Phosphorus may play an important role in photosynthesis, respiration, metabolism of sugars, cell division, membrane plasticity and transfer of genetic information (Buchanan et al. 2015). All these variables may contribute to higher levels of resistance to pathogens.

The balance between the water and supplied nutrients are environmental variables capable of being manipulated, besides influencing productivity and the disease progress rate in the field. As a viable option for the management, besides saving on the application of chemical products, it will minimize problems, such as resistance to pathogens and effects from the biennial coffee plantation.

In view of the above, the aim of this study was to assess the progress of brown eye spot on coffee plantations under different drip irrigation and fertilization management.

Material and methods

Characterization of the experimental area

The test was conducted from 16 March 2012 to 3 June 2014 in a coffee plantation of the Federal University of Lavras (MG) at 21°13'S latitude, 45°00'W longitude and 919 m altitude. The time interval was necessary to evaluate the biennial production of coffee crops (Pereira et al. 2011). The climate was humid subtropical (Cwa) according to the Köppen classification, with rainfall predominating in summer and dry winter. The soil of the experimental area was classified as dystrophic red latosol.

The coffee cultivar was MGS Travessia, susceptible to brown eye spot, with 8 years of age at the start of the experiment and spacing of 2.60 m between rows and 0.60 m between plants.

Experimental design and treatments

The experimental design was a randomized block design, with 12 treatments and three replications, in a 3 × 4 factorial design. There were three fertilization managements and four irrigation managements. Each block consisted of three adjacent rows. The plots were composed of 10 plants, with the eight central plants used for measurements.

Irrigation treatments were the control without irrigation (WI), irrigation all year (IT), suspension of irrigation for 30 days in July (I30), and for 70 days between July and September (I70). Irrigation was interrupted in I30 and I70 in the drier periods to provide greater flowering uniformity and to guarantee a higher percentage of ripe fruits (Souza et al. 2014).

Three fertilization treatments were used. The first one was performed based on the soil analysis and recommendations of the Soil Fertility Commission of the State of Minas Gerais (Guimarães et al. 1999), applying 300 kg ha^{-1} N and 225 kg ha^{-1} K_2O per year, without application of P_2O_5 (A). In the second treatment, 300 kg ha^{-1} P_2O_5, 550 kg ha^{-1} N and 550 kg ha^{-1} K_2O per year (B) were applied, and in the third, 550 kg ha^{-1} N and 550 kg ha^{-1} K_2O per year (C) were applied. The sources of the nutrients were urea (45% N), potassium nitrate (13% N and 44% K), and monoammonium phosphate (11% N and 60% P_2O_5). The application of phosphorus was done with 2/3 of the dose in the months September/October and 1/3 in January/February. The application of N and K was done with 2/3 of the dose between the months October and December and 1/3 in the months January and February.

Irrigation, fertilization and cultural practices

The irrigation shift was fixed (irrigation done on Tuesdays and Fridays) and the applied depth was defined based on the simplified water balance between two irrigations. Irrigation depths were defined by estimating crop evapotranspiration based on evaporation of the Class A tank (ECA) and the tank coefficients recommended by Doorembos and Pruit (1984) and culture, based on the plant age and the planting spacing, according to Allen et al. (1998). In the treatments with irrigation suspension, when it was restarted, the soil moisture was elevated to the field capacity condition and later followed up with the proposed management. All treatments were fertigated using Amiad® injection pump during the months October and February.

Micronutrient fertilization was foliar, according to the defined needs based on the leaf analysis performed in January of each year. The crops were kept free of weeds and insects through hand weeding and phytosanitary treatments, standardized for all plots.

Irrigation system and meteorological data used

The localized drip irrigation system was used and consisted of a reservoir with a capacity of 5000 L, control head composed of centrifugal pump, sand and disc filters, fertilizer injection pump, manometer and connections, main line of tube and PVC shunt, and side lines of polyethylene with drippers every 0.50 m.

Average daily climatic data, maximum, average and minimum temperature, relative humidity, radiation and rainfall were collected in a weather station located at the Federal University of Lavras. The monitoring period occurred simultaneously with evaluations of brown eye spot of the coffee tree.

Assessment of disease severity and area under the severity progress curve of brown eye spot (AUDPC)

A total of 21 assessments on the disease severity were performed every 30 days, from 16 March 2012 to 3 June 2014. Twelve leaves/plant were sampled in the eight central plants, totaling 96 leaves/plot. Leaves were randomly evaluated by non-destructive method in the middle third of the plant, between the third and fourth pair of leaves from plagiotropic branches. The severity of brown eye spot was calculated as percentage of leaves with disease symptoms.

The average index of disease severity in the 36 plots was plotted for the duration of the experiment, together with the averages of the climatic variables and the cumulative rainfall during the evaluated period. We used the average of the climatic variables data collected during the 30 days prior the disease assessment.

The data obtained from disease severity on coffee leaves were integrated in AUDPC, according to the equation proposed by Shaner and Finney (1977).

$$\mathrm{AUDPC} = \sum_{i=1}^{n-1} \frac{(Y_i + Y_{i+1})}{2} * (T_{i-1} - T_i)$$

Therefore:

AUDPC Area under the disease progress curve of brown eye spot,
Yi disease severity in the i-th observation,
Ti time in days in the i-th observation,
n total number of observations.

AUDPC values were calculated for three periods, from March to November 2012, from December 2012 to August 2013, and from September 2013 to June 2014, as well as the conjunction of the entire period.

Evaluation of foliage and harvesting

The foliage of plots was evaluated simultaneously to the assessment of brown eye spot. Grades from 1 to 5 were attributed according to the plant foliage, being 1 (0 to 20%), 2 (21 to 40%), 3 (41 to 60%), 4 (61 to 80%), and 5 (81 to 100%) (Boldini 2001). The experimental plots were harvested manually on a cloth, starting with 90% of ripe fruits. After the harvesting, the total coffee was recorded in L/plant or per plot. Afterwards, productivity was estimated for the harvest from the years 2012, 2013 and 2014 in 60-kg bags.ha^{-1} using the following formula:

$$P = QLP \times \frac{NP}{500}$$

P Productivity in 60-kg bags.ha^{-1},
QLP Quantity of liters per plant,
NP Number of plants per hectare.

Statistical analysis

The assumptions of the analysis of variance were verified by normality tests of Shapiro-Wilk, homogeneity of Bartlett and independence of Box and Pierce. They were not significant, so no data transformation was required.

The analysis of variance (ANOVA) was then performed in a 3 × 4 factorial design for the AUDPC variable per evaluation period. Significant variables in the F test of ANOVA were compared using the Scott-Knott clustering. For the statistical analysis of the experiment, the Sisvar® software (Ferreira 2008) version 4.0 was used.

Results

Progress curve of brown eye spot

There was variation in the average disease intensity and the foliage among the evaluation periods (Fig. 1). The highest average severity of brown eye spot was observed on 29 May 2012 (4.2%), 28 June 2013 (10.2%), and 3 June 2014 (9.8%) (Fig. 1a).

In the first two periods, after these dates with higher severity, there was a large reduction in foliage and in disease severity (Fig. 1a).

AUDPC in the different evaluation periods

There were lower values of AUDPC in the years 2012 and 2014, with an index of 631.5 and 789.8, respectively. In 2013, there was the highest AUDPC (1266.0), at least 60% higher compared with the other years of disease evaluation ($P < 0.05$) (Fig. 2).

The interaction between irrigation and fertilization was not significant ($P > 0.05$), so the irrigation and fertilization where analyzed separately. Regarding irrigation management, there was a statistical difference ($P < 0.05$) for the different

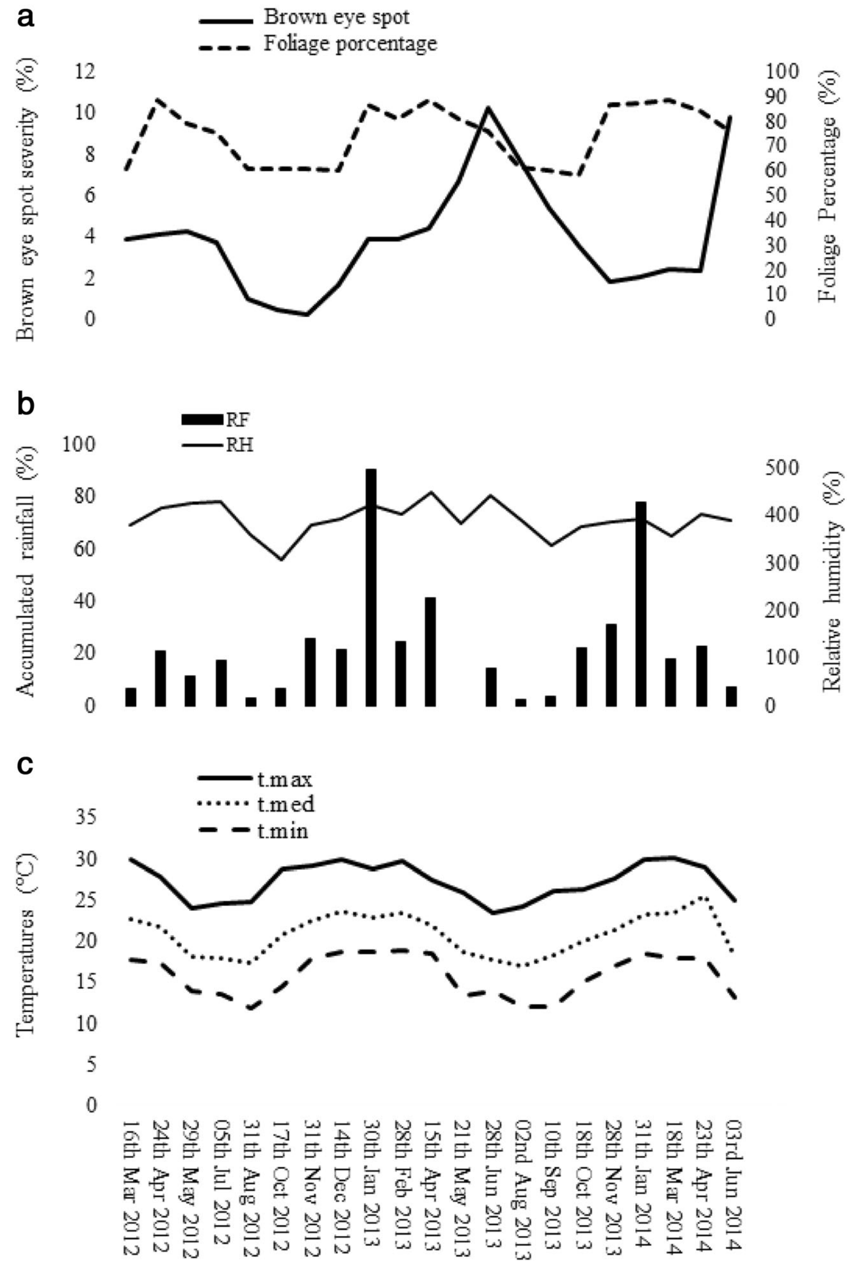

Fig. 1 Progression curve of the severity of brown eye spot and the average foliage percentage (**a**), monthly averages of climatic variables, relative humidity (RH) and accumulated rainfall (RF) (**b**), and maximum (TMAX), minimum (TMIN) and average (TMED) temperatures (**c**). From March 2012 to June 2014

irrigation management only in the year 2012. A higher AUDPC (870.4) was observed in the treatment with irrigation suspension for 70 days (I70) between the months July and September when compared with all other treatments ($P < 0.05$) (Table 1). There was no statistical difference between fertilization treatments ($P < 0.05$).

Coffee productivity

There was no significant interaction between irrigation and fertilization, but there was a statistical difference ($P < 0.05$) for fertilization individually in 2012 and in the accumulated production. There was lower productivity in the treatment with traditional fertilization based on the soil fertility analysis (A). Different average coffee productivities were observed between the years 2012, 2013, and 2014. In the years 2012 and 2014, there was lower productivity, with 38.2 and 46.8 60-kg bags.ha^{-1}, while the productivity in 2013 was 63.1 60-kg bags.ha^{-1} (Table 2).

Discussion

The disease intensity varied over the evaluated period. The highest severity occurred in average monthly temperatures of 18.0 °C and cumulative monthly rainfall of 58.9 mm in

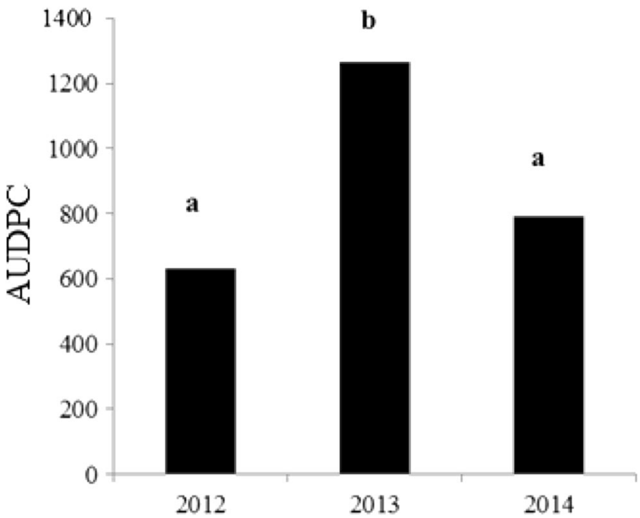

Fig. 2 Area under the incidence progress curve of BES (AUDPC) of coffee between the years 2012, 2013, and 2014

the years 2012, 2013 and 2014. Brown eye spot had a higher severity in the months with lower temperatures and rainfall, even with negative correlations, mainly in the treatment of 70 days without irrigation. Other authors reported a higher disease severity during this period under these conditions. Talamini et al. (2003) found higher severity between May and September in an experiment with different nitrogen, potassium and phosphorus plots by fertigation, with a severity of up to 35.0%. Similarly, Custódio et al. (2014) in coffee plantation irrigated by sprinkler also observed average rates of 11.0% of disease severity in the months July and September,

Table 1 Values of AUDPC for the four irrigation treatments and for the three fertilization treatments

Irrigation management[a]	AUDPC			
	2012	2013	2014	average
WI	486.4 a	1609.7 a	722.2 a	939.4a
IT	549.9 a	1156.6 a	834.0 a	846.8 a
I30	619.3 a	1093.4 a	870.2 a	861.0 a
I70	870.4 b	1204.2 a	732.8 a	935.8 a
Fertilization management	AUDPC			
	2012	2013	2014	average
A	544.6 a	1338.5 a	809.2 a	897.4 a
B	593.3 a	1258.3 a	716.7 a	856.1 a
C	756.6 a	1201.0 a	843.4 a	933.7 a

[a] Control without irrigation (WI), irrigation all year (IT), suspension of irrigation for 30 days in July (I30), suspension of irrigation for 70 days between July and September (I70). 300 Kg ha^{-1} N and 225 Kg ha^{-1} K2O/crop year, without P_2O_5 (A), 300 kg ha^{-1} P_2O_5, 550 kg ha^{-1} N and 550 kg ha^{-1} K_2O/crop year (B), 550 kg ha^{-1} N and 550 kg ha^{-1} K_2O/crop year (C). Averages followed by the same letters do not differ among themselves by Scott-Knott test ($P < 0.05$)

with average temperature of 22.0 °C and accumulated rainfall of 39.0 mm. The average temperatures observed in the experiments mentioned above were below those proposed by Echandi (1959) and López-duque and Fernadez-borrero (1969). According to these authors, the optimum temperature for conidial germination and fungus growth is 24.0 and 30.0 °C, respectively. According to Echandi (1959), 2 hours of leaf wetting are sufficient for the germination of conidia, i.e., only the dew in the early hours of the morning may be enough to provide the infection in periods of lower rainfall, as observed in the experiment. The variation in the dates of greatest occurrence may be related to the absence of rainfall in the period, imbalance foliar feeding and favorable temperatures to the pathogen.

The highest severity of brown eye spot (18.7%) on 3 June 2014 was found in the treatment with irrigation suspension for 70 days between the months June and September and addition of 550 kg of N and K_2O ha^{-1}/crop year (I70C). The water deficiency (37.6 mm) in the period, together with the non-complement of irrigation, probably predisposed the plant to fungus infection. Moreover, this was the single treatment that differed statistically ($p < 0.05$) from the others, with greater intensity of brown eye spot and AUDPC of 870.49 in the period between March and November 2012. The function of fertigation is to provide water and nutrients through the roots to the shoot of plants, contributing to reduce the disease intensity. Water is the main constituent of the plant tissue, being necessary for the absorption, transport and translocation of nutrients (Taiz et al. 2014). Water deficiency culminates in nutritional imbalance, affecting the growth, development and productivity of crops (Pozza and Pozza 2012; Custódio et al. 2014). Probably, the lack of water in this treatment in critical seasons of the culture made it difficult to translocate the nutrients to several organelles, affecting essential processes, such as the synthesis of nucleic acids, amino acids, proteins, as well as photosynthesis and cellular respiration, which are indispensable processes for the energy production, thus reducing the formation of horizontal resistance barriers of plants (Pozza and Pozza 2012; Marschner 2012).

In relation to phosphate fertilization, for many years the coffee tree was considered a plant that did not respond to the application of phosphorus doses in its production phase (Reis et al. 2011, 2013). The availability of P is mainly affected by water stress conditions, since besides being fixed in the clay fraction, it is poorly mobile in the soil solution. However, some studies have described the importance of this nutrient in the coffee production stage. Guerra et al. (2007) studied crops in which with an increase of P_2O_5 in October, high growth rates were observed, such as long nodes and green leaves in the later months. Reis et al. (2011) worked with irrigated coffee trees and observed a response of phosphate fertilization in the crop production phase, with gains of up to 138% by applying 400 kg of P_2O_5/ha. Phosphorus plays

Table 2 Averages for coffee productivity in bags of 60 kg/ha^{-1} in the years 2012, 2013 and accumulated of the 2 years, due to irrigation and fertilization managements

Irrigation management[a]	Productivity (60-kg coffee green bags.ha^{-1})				
	2012	2013	2014	Accumulated	Average
WI	35.7 a	65.6 a	33.2 a	134.5 a	44.8 a
IT	35.0 a	62.9 a	50.4 a	148.3 a	49.4 a
I30	33.3 a	58.7 a	49.7 a	141.7 a	47.2 a
I70	31.3 a	66.3 a	54.2 a	151.8 a	50.6 a
Fertilization management	Productivity (60-kg coffee green bags.ha^{-1})				
	2012	2013	2014	Accumulated	Average
A	29.2 b	52.6 a	39.8 a	121.6 b	40.5 b
B	33.8 a	51.3 a	52.9 a	137.9 a	46.0 a
C	41.1 a	59.9 a	47.9 a	148.9 a	49.6 a
Average treatments	Productivity				
	2012	2013	2014	Accumulated	Average
	38.2 c	63.1 a	46.8 b	148.1	49.3

[a] Control without irrigation (WI), irrigation all year (IT), suspension of irrigation for 30 days in July (I30), suspension of irrigation for 70 days between July and September (I70). 300 Kg ha-1 N and 225 Kg ha-1 K2O/crop year, without P2O5 (A), 300 kg ha-1 P2O5, 550 kg ha-1 N and 550 kg ha-1 K2O/crop year (B), 550 kg ha-1 N and 550 kg ha-1 K2O/crop year (C). Averages followed by the same letters do not differ among themselves by Scott-Knott test at 5% probability

structural, physiological and biochemical functions essential to the plant and is part of its energy molecule, the ATP (adenosine triphosphate) (Buchanan et al. 2015). When properly managed, this nutrient improves the physiological characteristics of the plant and can increase its productivity, as well as reduce the intensity of coffee diseases (Pozza and Pozza 2012; Custódio et al. 2011).

In the literature, there are several studies relative to the influence of irrigation on the progress of coffee diseases, but few studies are evaluating its influence with the phosphorus management. Some authors reported higher disease intensities under water stress conditions. Miranda et al. (2006) verified severity of up to 17.0% of coffee leaf rust in non-irrigated plots and 6.0% where the applied depth was 60.0% ECA. Talamini et al. (2003) observed higher intensities of brown eye spot in the non-irrigated treatment (9874.7), being reduced to 4984.6 when coffee was irrigated from July to October. As well as Paiva et al. (2013), these authors verified severity of up to 30.0% of brown eye spot in the control, with a reduction of 27.0% in disease severity when irrigation was started with soil tension of 20 Kpa. However, irrigation in areas or years of good rainfall for coffee, with a rainfall index above 1200 mm and well distributed (Camargo 2010) may not provide a reduction in the brown eye spot intensity due to the adequate supply of water via rainfall to the control (Paiva et al. 2011). For coffee leaf rust, Talamini et al. (2003) and Miranda et al. (2006) evaluated the cultivar Acaiá cerrado for 5 years and did not find difference in the severity between the water depths (0, 40, 60, 80, and 100% ECA) provided by drip irrigation because rainfall was considered ideal for the culture and disease progress. In other words, irrigation can contribute to reduce the disease severity when rainfall is lower than that required for coffee or poorly distributed throughout the year, especially in densified areas with high productivity in oxisols. The water deficit has been frequent in recent years even in areas suitable for planting coffee trees due to climate change (Dantas et al. 2007; Chalfoun et al. 2001).

In the conditions performed in this experiment, an increase in leaf fall and reduction of brown eye spot was observed in the month after the highest disease intensity and harvesting. Certainly, the lost leaves were infected by *C. coffeicola*. The high intensity of brown eye spot may have activated the ethylene production, The synthesis of this hormone activates genes to produce enzymes present in the cell wall, such as cellulales and polygalacturonases, leading to leaf abscission and early ripening of fruits (Taiz et al. 2014). Furthermore, the harvesting operation maximized this defoliation due to the harvest action. Consequently, some plots had only 25% of foliage. Additionally, diseases reduce the photosynthetic capacity of coffee trees, affect their vegetative growth, diminish the formation of nodes, damage the formation of their floral buds, and reduce the size of their fruits, compromising their productive capacity for the next harvest (Pozza et al. 2010).

High productivities also unbalance the plants nutritionally, predisposing them to greater attacks by pathogens. In this experiment, a higher AUDPC (1266.0) was observed in 2013, accompanied by higher productivity, 63.2 60-kg bags.ha^{-1}. On the contrary, in 2012 and 2014, the AUDPC and productivity were lower, with disease intensity of 631.5 and 798.8 and productivity of 38.2 and 46.8 60-kg coffee green bags.ha^{-1} respectively, reflecting the biennial characteristic of the coffee.

In conclusion, the highest disease intensities occurred between May and July with accumulated average temperature and rainfall of 18.0 °C and 58.9 mm, respectively. The suspension of irrigation for 70 days between July and September can favor brown eye spot. Coffee productivity can be increased with high rates of NK fertilizer. P as used in this work did not influence brown eye spot or productivity.

Acknowledgments To National Council for Scientific and Technological Development (CNPq), the Foundation for Research Support of the State of Minas Gerais (FAPEMIG), the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Institute of Science and Technology of Coffee (INCT-Café) for supporting the research.

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