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Fuzzy Logic System Modeling Soybean Rust Monocyclic Process

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1. Introduction

The soybean rust (*Phakopsora pachyrhizi* H. Sydow & P. Sydow) was reported in soybean (*Glycine max* L. Merrill) in many tropical and subtropical regions, causing significant reductions in productivity and quality of seeds (Bromfield, 1984, Hartman et al., 2005; Kawuki et al., 2004; McGee, 1992, Medina et al., 2006, Sinclair & Backman, 1989; Vale, 1985, Yang et al., 1990, Yang et al., 1991; Yorinori & Lazzarotto, 2004), with losses of up to 70% in production (Bromfield, 1976). The rust occurs in almost all soybean fields in Brazil. The states with high occurrence of the disease in 2003/04 were Mato Grosso, Goias, Minas Gerais and São Paulo. Considering Brazilian states in 2002/03, soybean rust caused losses of 4.011 million of megagrams or the equivalent of US$ 884.25 million, while in 2004, the losses were approximately US$ 2.28 billion (Yorinori & Lazzarotto, 2004).

The success of pathogen infection depends on the sequence of events determined by spore germination, appressoria formation and penetration. Each of these events, the subsequent colonization and sporulation, are influenced by biotic factors such as pathogen-host and abiotic environment. Among abiotic factors, temperature and leaf wetness play a crucial role, especially in the monocyclic germination, infection and colonization of *P. pachyrhizi* in soybeans. Thus, several studies were conducted to model the effects of temperature and humidity on the disease progress for Brazilian cultivars (Vale, 1984, Vale et al., 1990) and for different cultivars adapted to other countries (Batchelor et al., 1997, Kim et al., 2005, Marchetti et al. 1975; Melching et al. 1989; Pivonia & Yang, 2004, Reis et al., 2004). According to Sinclair & Backman (1989), the range of optimum temperature for infection is 20 °C to 25 °C. Under these conditions, with the availability of free water on the leaf surface, the infection starts after 6 hours of the deposition of the spore (Marchetti et al., 1975; Melching et al. 1989; Vale et al., 1990). However, after 12 hours (Marchetti et al. 1975; Melching et al., 1989) up to 24 hours of leaf wetness (Vale et al., 1990) was more successful in establishing infection (Sinclair & Backman, 1989). Therefore, such studies are important for estimating the potential occurrence and formulate strategies to control disease in geographic regions not yet reported (Pivonia & Yang, 2005) and to investigate the potential of spreading in major producing regions throughout the months of the year (Alves et al., 2006; Pivonia & Yang, 2004).

Linear regression approaches (Vale et al., 1990), nonlinear regression (Reis et al., 2004), artificial intelligence techniques, such as neural networks (Batchelor et al., 1997, Pinto et al., 2002) and fuzzy logic (Kim et al., 2005), were used to model the influence of abiotic variables on the disease progress. However, in the case of using regression and neural networks, there is a need to perform data collection for the best fitting models (Reis et al., 2004) and network training (Batchelor et al., 1997). On the other hand, considering fuzzy logic technique, quantitative measures are no longer urgently needed to develop a model (Kim et al., 2005), notwithstanding the choice of these observations are used in the modeling process (Mouzouris & Mendel, 1997). In this context, fuzzy logic was applied to model physical, chemical and biological process, with uncertainty and ambiguous nature (Kim et al., 2005, Massad et al. 2003; Schermer, 2000; Uren et al., 2001).

Other features that justify the application of fuzzy logic systems (FLS) are related to the flexibility of the technique, ease of understanding the concepts, ability to model complex nonlinear functions, development based on the expertise of specialists, integration with other automation techniques and finding support in the natural language used by humans (Cox, 1994; Tanaka, 1997).

Likewise, there is no precise measurements of the influence of other variables such as soil fertility, resistant cultivars, climatic variables, management practices in the progress of the disease, being necessary to create a subjective measure to assess the potential progress of the disease.

Considering the importance of the soybean crop in Brazil, as well as the risk caused by the rust and the losses due to its occurrence, it is necessary to know epidemiological aspects of the disease in Brazilian cultivars in order to enable disease intensity prediction. Therefore, the objective of this work was to study the effects of temperature and leaf wetness on the monocyclic process of soybean rust in cultivars Conquista, Savana and Suprema, based on a fuzzy logic system and nonlinear regression models.

2. Material and methods

The phases of problem selection, development, evaluation and implementation were used to develop the FLS.

2.1 Problem selection

As criteria to study the application of a FLS for estimating soybean rust, there were considered the selection of the problem, seasonal occurrence, the existence of experts and literature in the area, the soybean crop importance and the ease of acquiring information. In the prototype development phase, information from the literature about the epidemiology of the disease and experts in the field were consulted (Batchelor et al., 1997; Bromfield, 1984, Kim et al., 2005, Marchetti et al., 1975; Melching et al., 1989; Pivonia & Yang, 2004, Reis et al., 2004; Valley, 1984, Vale et al., 1990). Some important aspects were considered in the design, such as simplicity to facilitate its subsequent implementation, to be based on knowledge and experience of experts in order to produce accurate and flexible results and the possibility to incorporate new variables (Von Altrock, 1995; Zadeh, 1965).

2.2 Development

In the early stage of development, membership functions were defined into five categories related to the variables temperature, leaf wetness, and area under the disease progress curve, classified as very low, low, medium, high and very high, in order to constitute the fuzzy sets. It was specified a set of if-then rules, with the input and output variables to form the inference mechanism (Tanaka, 1997). The system used the implication operator Min of Mamdani, because it was intuitive and widely accepted to translate the human experience (Driankov et al., 1993), and the limited sum composition method (Cox, 1994), chosen due to the nature of the rules, as each one defined an increase or decrease in the occurrence of rust (Vargens et al., 2003). When compared to the operator max, which considers only the maximum value of relevance, the limited summation method was more suitable, similar to that found in the study of Vargens et al. (2003). At the final stage of development, corrections were made to confirm the internal logic and its full operation based on expert knowledge, references in the area, fuzzyfication, inference and defuzzification processes (Figure 1).

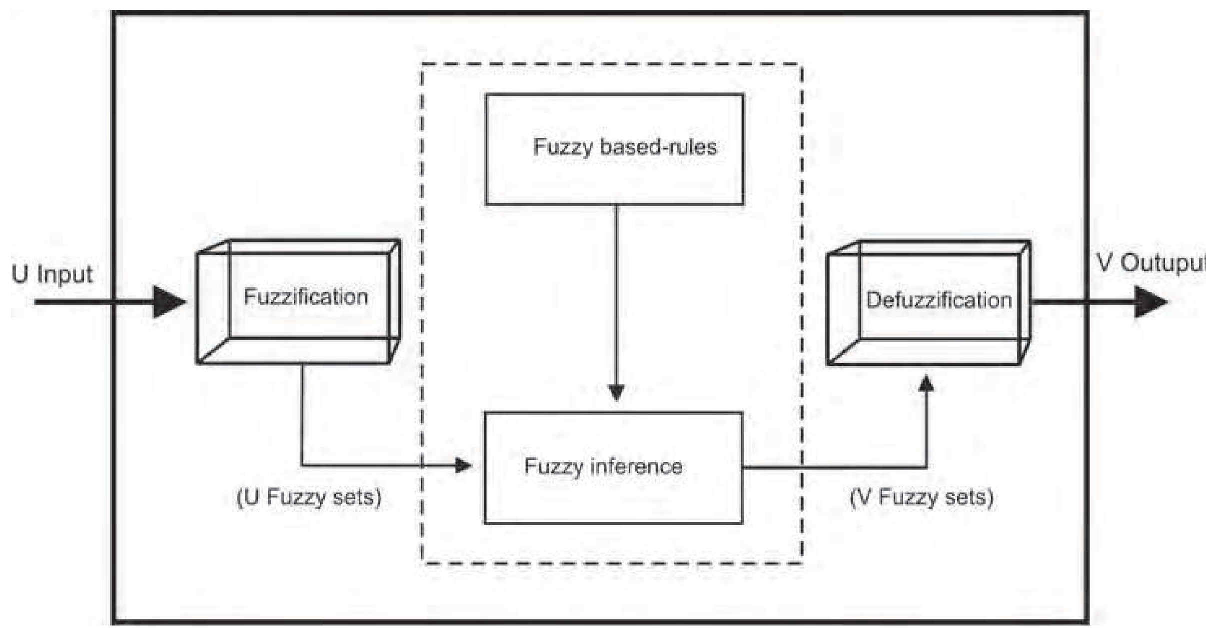

Fig. 1. Structure of a logic fuzzy system (Adapted from Mouzouris & Mendel, 1997).

2.3 Validation

Data collection for the system validation was obtained through experiments conducted in growth chambers at the Laboratory of Epidemiology and Management of the Department of Plant Pathology, Federal University of Lavras (UFLA), Brazil. The experimental design was in blocks at random arrangement of 4 x 5 factorial treatments, with three replications, four temperatures (15 ºC, 20 °C, 25 °C and 30 °C) and five leaf wetness periods (0, 6, 12 , 18 and 24 hours). After designing the layout, soybean cultivars Conquista, Savana and Suprema were planted in pots containing 5 kg of soil mixture, sand and organic matter (manure) in the proportion 2:1:0.5. Thinning was performed 15 days after planting, leaving two plants per pot. The plants were kept at green house until V3 vegetative stage, according to the soybean phenological scale proposed by Ritchie et al. (1982). The inoculum of the fungus was obtained by collecting *P. pachyrhizi* uredospores directly from Conquista diseased plants, in a greenhouse, at the UFLA experimental campus, and stored in liquid nitrogen (-180 °C). Test was performed to verify the viability of the inoculum before the inoculation, which presented 89% germination.

The inoculation was done by spraying all the leaves with a suspension at a concentration of 10^4 uredospore of *P. pachyrhizi*.mL^{-1} until runoff. For the different periods of leaf wetness, the plants recently sprayed with the suspension of uredospore were kept in a moist chamber for the duration of each treatment, wrapped in clear plastic bags. In the treatment of zero hours of leaf wetness, the plants were taken to the growth chambers without moist step, allowing the rapid drying of the sprayed suspension. During the experiment, irrigation was accomplished by depositing water directly in the lap of the plants. From the 6th day after inoculation, there were four disease severity (% leaf area with lesions) and incidence (% of leaflets core of all trifoliate leaves of plants) every three days, depending on the onset of signs. The severity and incidence of rust were recorded in the central leaflet of all trifoliate leaves of each plant. The severity was obtained using Bromfield (1984) scale: where score 0 = 0%, 1 = 0.15%, 2 = 1.0%, 3 = 2.5%, 4 = 8.0%, 5 = 13.0%. By having the data of disease severity, the area under the curve of progress of disease incidence (AUDPCI) and severity (AUDPCS) was calculated, according to Campbell & Madden (1990), for each combination of temperature and leaf wetness inside of each cultivar susceptible to disease (Zambenedetti, 2005).
After obtaining the data, it was proceeded the analysis of variance for AUDPCI and AUDPCS, according to a factorial design between temperature and leaf wetness. The significant variables in the F test were subjected to analysis of nonlinear regression to obtain equations to represent the effects of the interaction of temperature and leaf wetness duration on the rust intensity (Figure 2). It is noteworthy that the dependent variable in the case of FLS was named as area under the disease progress curve (AUDPC), since in this case, both results of AUDPCI and AUDPCS were considered for the FLS development. The FLS was validated using Pearson correlation coefficients and linear regression between estimated and observed values of diseased plants, comparatively with the nonlinear regression models.

2.4 Implementation

After the validation phase, the implementation phase was proceeded with the use of a geographic information system and geostatistics (Burrough & McDonnell, 1998). Thus, the FLS was used to estimate the disease based on observations of mean monthly temperature of 39 weather INMET stations, referring to Climatological Normals (1961-1990) (BRASIL, 1992) for the month of January, simulating the occurrence of leaf wetness for 12 hours at all considered stations, because there is no historical data of this variable (BRASIL, 1992). As the number of weather stations available in Minas Gerais and surrounding regions are scarce, the co-kriging technique (Isaaks & Srivastava, 1989) was used to improve the quality of the data interpolation and to increase the spatial resolution of the estimates, through a database of altitude, latitude and longitude, in a regular 1 km grid within the boundaries of the Minas Gerais state, considering the digital elevation model of the surface with a spatial resolution of 90m (NASA, 2005). After, co-kriging was used to map the potential spatial progress of the disease (Figure 3). Co-kriging technique was chosen to explore the known influence of altitude, latitude and longitude in the variation of temperature (Sediyama Mello Jr., 1998), as well as in the occurrence of disease (Yang & Feng, 2001), and to improve the spatial resolution of the estimates.
After mapping rust, the same co-kriging procedure was applied to characterize the climate of Minas Gerais, in order to verify the relationship between the intensity of rust and moisture annual Thornthwaite index (Iu), as well as the annual potential

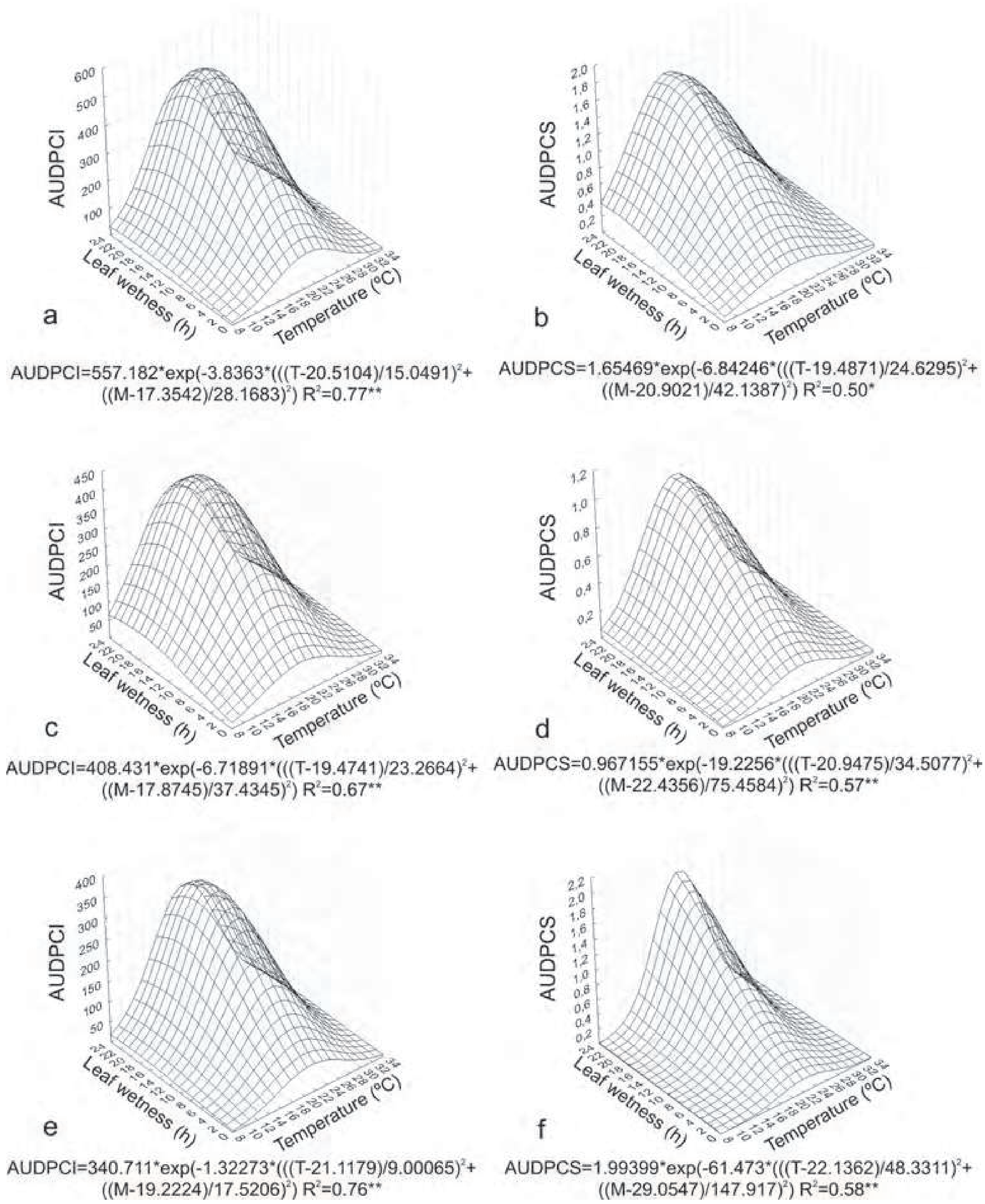

Fig. 2. Nonlinear regression models used to represent the incidence progress (AUDPCI) (a, c, e) and severity curves (AUDPCS) (b, d, f) of soybean rust in cultivars Conquista (a, b), Savana (c, d) and Suprema (e, f).

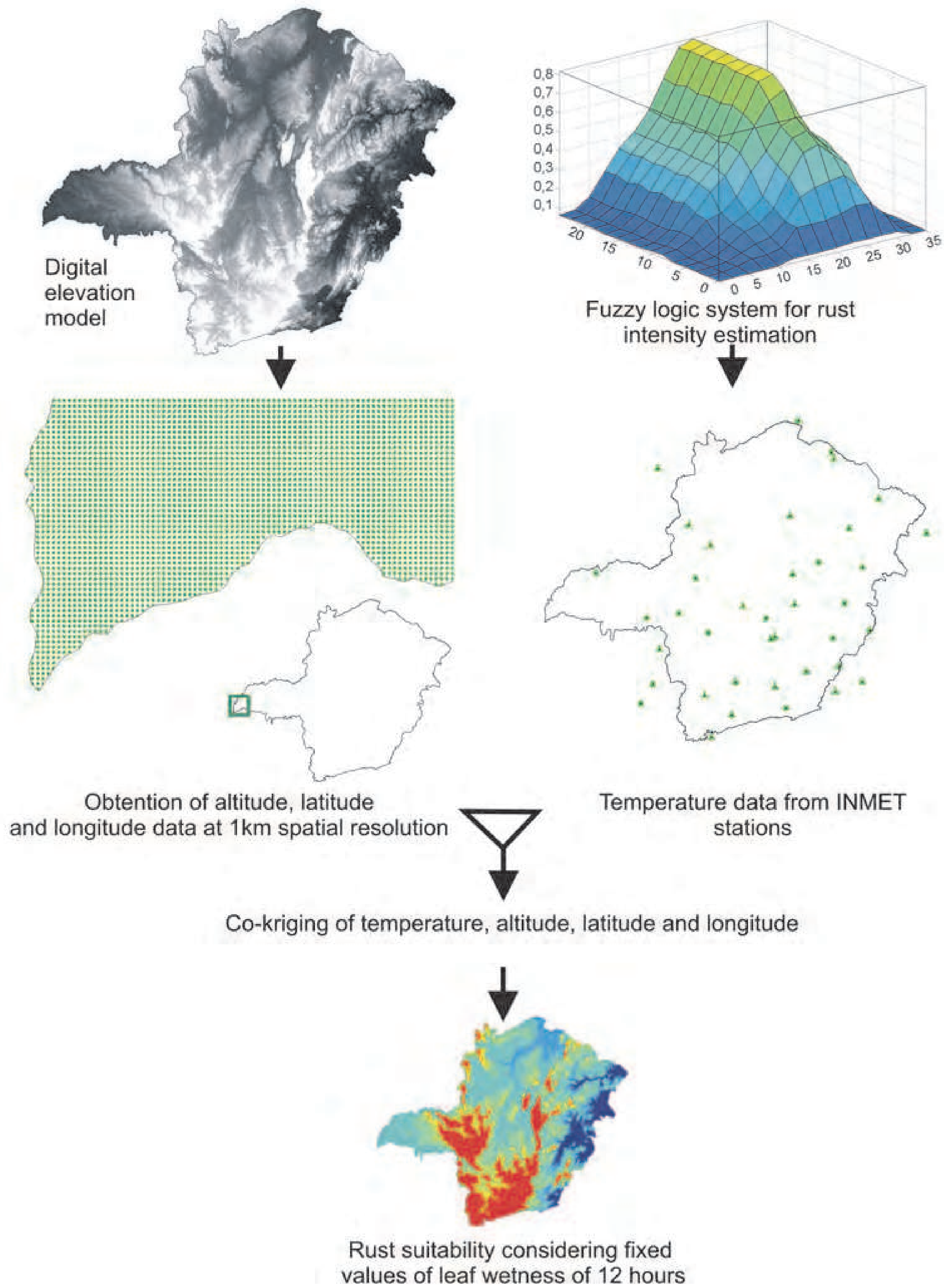

Fig. 3. Scheme used to implement the fuzzy logic system.

evapotranspiration (ETp) (Thornthwaite, 1948; Thornthwaite and Mather, 1955). The climatic characterization was based on climatological data of temperature and rainfall referring to 32 locations INMET (BRAZIL, 1992). For this, the ETp was estimated by Thornthwaite method based on average monthly values of air temperature and, thereafter, in possession of rainfall and considering the storage capacity of soil water equivalent to 100 mm (mean value for most crops), the climatic water balance was calculated. Based on values obtained from the excess and deficit water balance, it was possible to estimate the water index and index of aridity, in order to obtain the Iu, for each location. It is noteworthy that the method of ordinary kriging was used in a comparative manner with co-kriging to estimate areas favorable to rust in Minas Gerais in order to compare the quality of the estimates of both methodologies.

3. Results and discussion

In the construction of the FLS, the input and output variables were divided into five categories, according to information from experts, and were classified according to the proximity of the universe of discourse. For example, in a position of fuzzy sets in the universe of high temperatures, and fuzzy sets in the universe of low duration of leaf wetness, implied unfavorable conditions to the progress of soybean rust, characterized by membership functions (Figure 4). Then, it was specified a set of rules based on expert knowledge, according to the influence of temperature and leaf wetness on disease (Table 1), to form, together with the fuzzy sets, the inference system (Figure 5). Then, a response surface of the FLS was generated for the input and output variables (Figure 6). At the end of the development phase, tests were performed with data in order to verify full operation of the FLS, according to an appropriate structure to process input data of temperature and leaf wetness, giving a response concerning the area under the disease progress curve consistent with the literature (Batchelor et al., 1997; Bromfield, 1984; Kim et al., 2005; Marchetti et al., 1975; Melching et al., 1989; Pivonia & Yang, 2004; Valley, 1984, Vale et al., 1990).

Subsequently, it was proceeded the model validation based on data from the experiment carried out under controlled conditions. In this case, models of nonlinear regression were fitted to data of rust incidence and severity in the cultivars Conquista, Savana and Suprema, to compare with the developed FLS. Thus, it could be observed higher correlation with observed estimates of FLS than the nonlinear regression models used to estimate the monocyclic process of rust in all the progress curves of incidence and severity, except for the severity variable of the Suprema cultivar (Figures 7, 8 and Table 2). This probably occurred because, in this particular case, the leaf wetness duration tended to increase until the period of 29 h, unlike the progress curves of the disease of the Savana and Conquista cultivars, which showed response of leaf wetness between 17 h and 23 h.

Similar to this study, Kim et al. (2005) developed an FLS for estimating the infection rate of apparent severity of soybean rust considering the results of 73 field experiments in Taiwan. However, in this case, the model was developed based on the average night temperature, maximum and minimum temperatures of the day, associated with biological criteria relating to the disease, in order to explain 85% of the progress and severity of the disease in TK 5 and G8587 cultivars, especially in the epidemic early.

Castañeda-Miranda et al. (2006) also developed an FLS to control the environment inside a greenhouse with meteorological variables, however, after validating step, the system was implemented in an electronic circuit integrated with FLS.

Similarly to the work of Castañeda-Miranda et al. (2006), it is expected to develop an electronic circuit to integrate the FLS developed in this study, with automated weather stations, to assist the decision making of farmers on the most appropriate time to conduct the integrated management of soybean rust.
After estimating the potential progress of the disease in INMET weather stations, co-Kriging was used to map potential suitability areas for disease occurence, considering better application of co-kriging method when compared to ordinary kriging (Table 2).

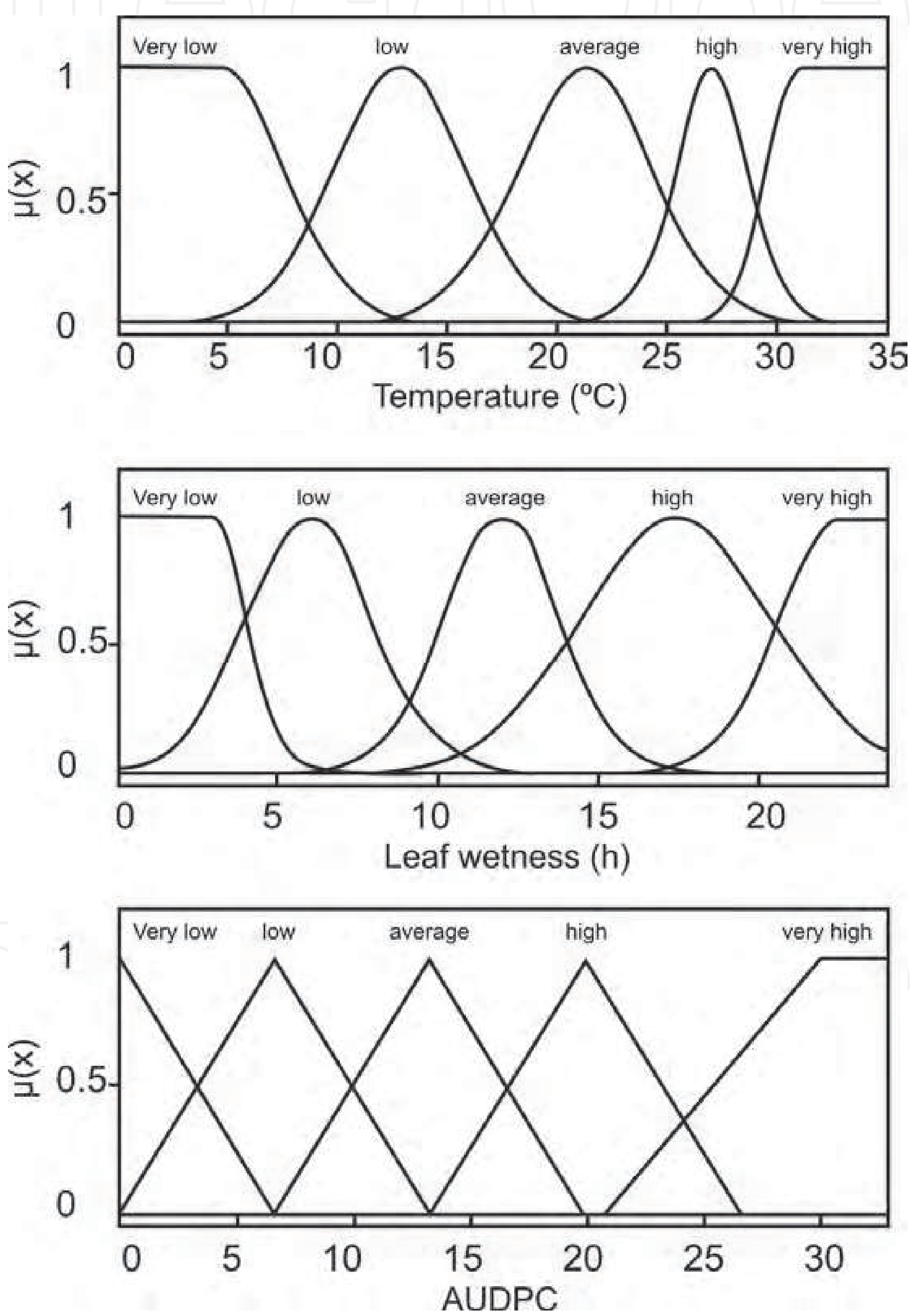

Fig. 4. Membership functions of temperature, leaf wetness, and area under the progress curve of soybean rust severity (AUDPC).

Rule Nº	If (Temperature - ºC)	and (Leaf wetness - hours)	Then (AUDPC)
1	-	Very low	Very low
2	Very high	Low	Very low
3	Very low	Average	Very low
4	Very low	High	Very low
5	Very low	Very high	Very low
6	Low	Low	Low
7	Low	Average	Average
8	Low	High	Average
9	Low	Very high	Average
10	Average	Low	High
11	Average	Average	Very high
12	Average	High	Very high
13	Average	Very high	Very high
14	High	Low	Average
15	High	Average	Average
16	High	High	Average
17	High	Very high	Average
18	Very high	Low	Low
19	Very high	Average	Low
20	Very high	High	Low
21	Very high	Very high	Very low

Table 1. Rules used to develop the FLS to characterize the monocyclic process of soybean rust

Other studies had applied the co-kriging to improve estimates based on covariates. For example, Desbarats et al. (2002) also used the co-kriging to estimate the water table of the aquifer Oak Ridges Moraine, in Ontario, Canada, in an area of 250 km^2, considering altitude as covariate. According to the authors, areas with higher water table occurred in areas of higher altitude.

Thus, it was observed the most favorable areas for disease in regions of higher altitude and less favorable areas, with the blue color, especially in the east and north of Minas Gerais (Figure 10). Based on a comparison of the ranges used for classifying the disease as high or low, relative to other rust forecasting models previously developed, there was consistency of the results according to the available literature. Therefore, to Sinclair (1975) and Bromfield (1981), the optimum temperature for infection by *P. pachyrhizi* was in the range of 18 °C to 21 °C if the leaf remain wet for at least 16 hours. Vale (1985), studying the cultivar Paraná, cited the value of 20 ºC and relative humidity above 90%, while Casey (1980), in Australia, determined temperature of 18 °C to 26 °C and extended periods of leaf wetness, approximately 10 hours per day, required to occur epidemics with high rates of progress and severity. In another review, Sinclair & Backman (1989) cited the optimum range of temperature for infection by *P. pachyrhizi* on soybeans from 20 °C to 25 °C, ie, all these authors observed temperatures around 20 ºC, although in some cases close to 25 °C as the optimum to occur higher intensity of the disease, with extended periods of leaf wetness . These differences may be related to the cultivars, as discussed earlier. Regarding the limiting temperatures, Casey (1980) quoted values above 30 °C and below 15 ºC, in dry conditions, ie with fewer hours of leaf wetness, as responsible for delaying the progress of the rust, while Bromfield (1981), quoted temperatures below 20 °C or above 30 °C. According to Vale et al. (1990), temperature and leaf wetness can be determinant for sporulation and reduction of the latent period of the disease in cultivar Paraná with 20 °C of temperature and 12 h to 24 h of leaf wetness, similar to the present study, with Conquista, Savana and Suprema cultivars. Marchetti et al. (1975) already studied the effect of rust in cultivar Wayne and observed that plants incubated at 27.5 ºC showed no infection regardless of the leaf wetness. Likewise, Melching et al. (1989), studying the effects of duration, frequency and temperature of leaf wetness periods on soybean rust in Taiwan, Wayne cultivar, found that after 8 hours of dew period between 18 °C and 26.5 °C, intensities of Injuries were 10 times higher than those in the 6 hours corresponding temperatures, despite the increased of leaf wetness from 12 to 16 hours did not result in significant increase in the rust intensity, even in favorable temperatures between 18 °C and 26.5 °C. There was no appearance of lesions at 9 °C and 28.5 ºC even in wet periods of 20 hours. Thus, because the Wayne cultivar and the rust race being probably adapted to conditions of latitude, longitude, different from Lavras, Minas Gerais, where *P. pachyrhizi* was first reported in Brazil (Bromfield, 1984), probably under conditions of temperatures above 28 ºC, there was no disease infection in Wayne cultivar, deviating from this study.

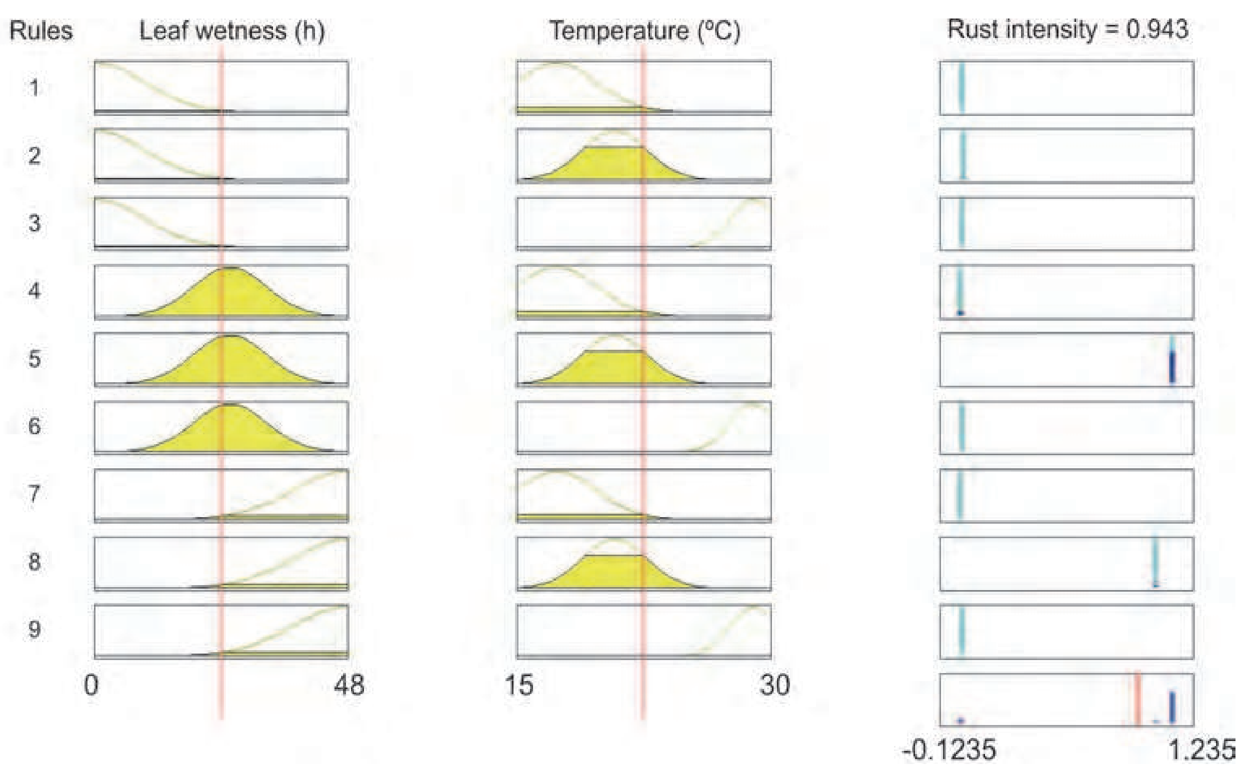

Fig. 5. Inference fuzzy diagram used to estimate the monocyclic process of soybean rust.

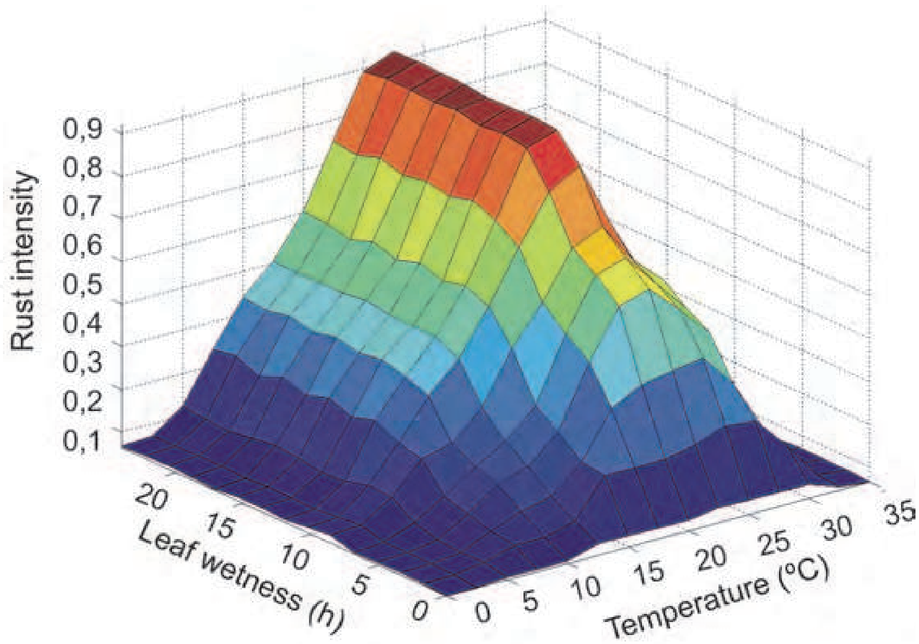

Fig. 6. Three-dimensional representation of the FLS model for estimating the monocyclic process of soybean rust, based on temperature and leaf wetness.

However, the climate model to predict soybean rust in soybeans in Brazil, Reis et al. (2004), based on data from Melching et al. (1989) with cultivar Wayne, suggested daily value of the probability of infection of uredospore with occurrence of infection even at temperatures around 29 °C with 16 hours of leaf wetness, and at lower temperatures of 9 ºC with 11 hours of leaf wetness, after nonlinear regression model fit to the observed data, disagreeing with the results of themselves Melching et al. (1989), but similar to situations found in the present study, with Brazilian cultivars adapted to the region of Lavras, Minas Gerais. Thus, despite having been reported in the literature similar responses of the disease with respect to temperature variation and leaf wetness duration, in some situations, differences in the intervals for disease suitability probably occurred due to host characteristics, differences between genotypes, vegetative stage, soil and plant nutrition, in order to justify the development of a subjective measure for evaluating the monocyclic disease process, as in the case of the present FLS.

After spatialize rust using the co-kriging technique, the same procedure was applied to characterize the climate of Minas Gerais, in order to verify the relationship between the intensity of rust with the moisture annual index of Thornthwaite (Iu), as well as the annual potential evapotranspiration (ETp) (Thornthwaite, 1948; Thornthwaite & Mather, 1955). Therefore, comparing the maps of disease severity (Figure 10) with those of ETp and Iu (Figure 11), it could be seen correspondence between areas of high rust intensity with lowest values of ETp and highest values of Iu. This relationship was also verified by the linear relationship of disease intensity with ETp and Iu, in the 39 INMET evaluated localities (Figure 12) and the negative correlation between the intensity of rust with the ETp ($r = -0.86457$, $p < 0.0001$) and positively with Iu ($r = 0.76682$, $P < 0.0001$). Another finding was the better application of co-kriging method when compared to kriging method, for detailing the spatial resolution of a database of macroclimatic variable scale from a database of covariates on mesoclimatic scale (Table 3). Likewise, based on climatic zoning, the planning and implementation of various areas such as industry, agriculture, transport, architecture, biology, medicine (Vianello & Alves, 1991), could be supported, in a sustainable manner (Mitchell et al., 2004), in order to minimize risks and impacts as well as negative effects of climate on natural resources (Machado, 1995; Hansen, 2002), based on appropriated decision-making.

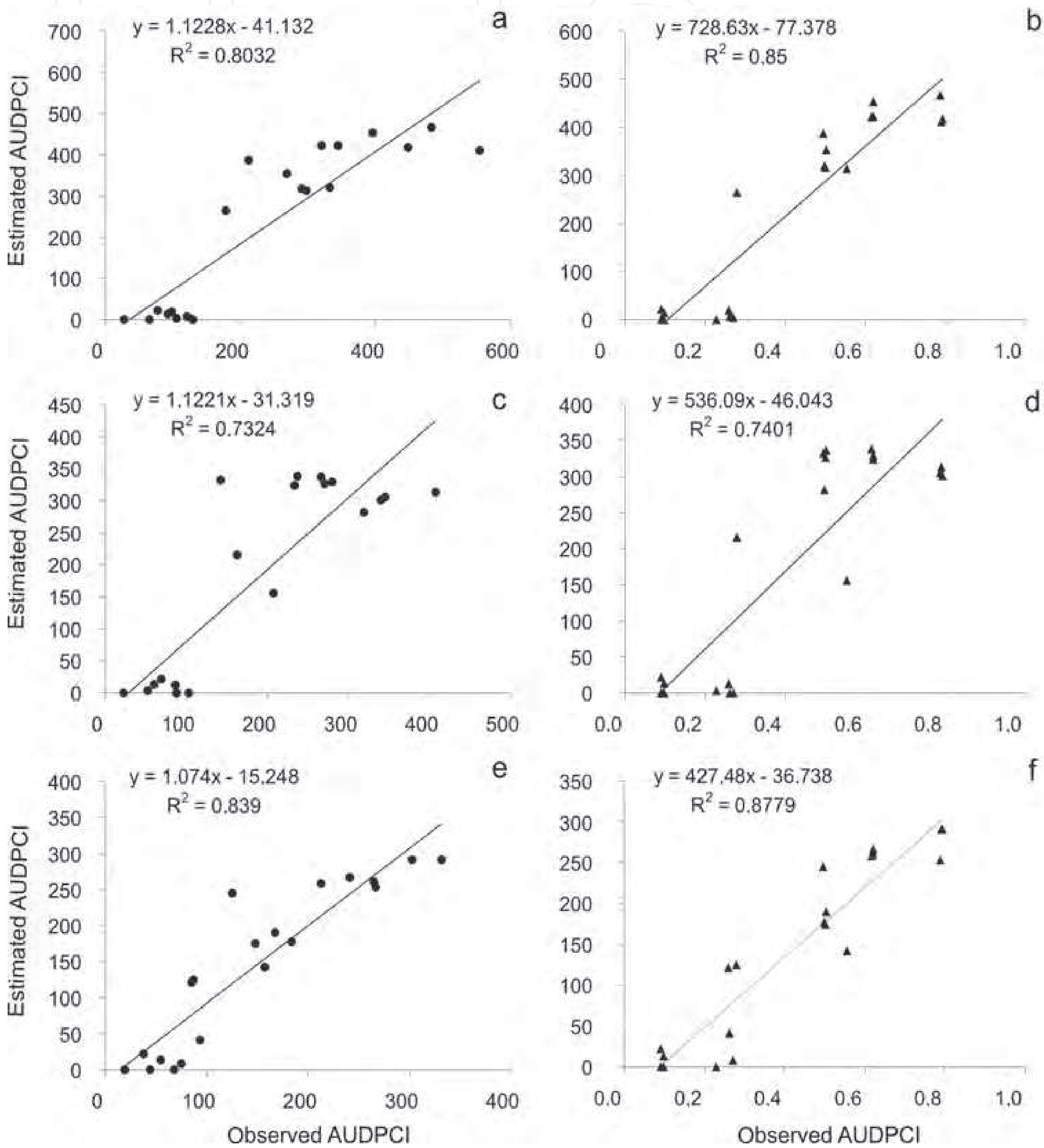

Fig. 7. Linear relationship between observed and predicted values of the area under the curve of incidence progress (AUDPCI) of soybean rust through models of nonlinear regression (a, c, e) and FLS (b , d, f) on the Conquista (a, b), Savana (c, d) and Suprema (e, f) cultivars.

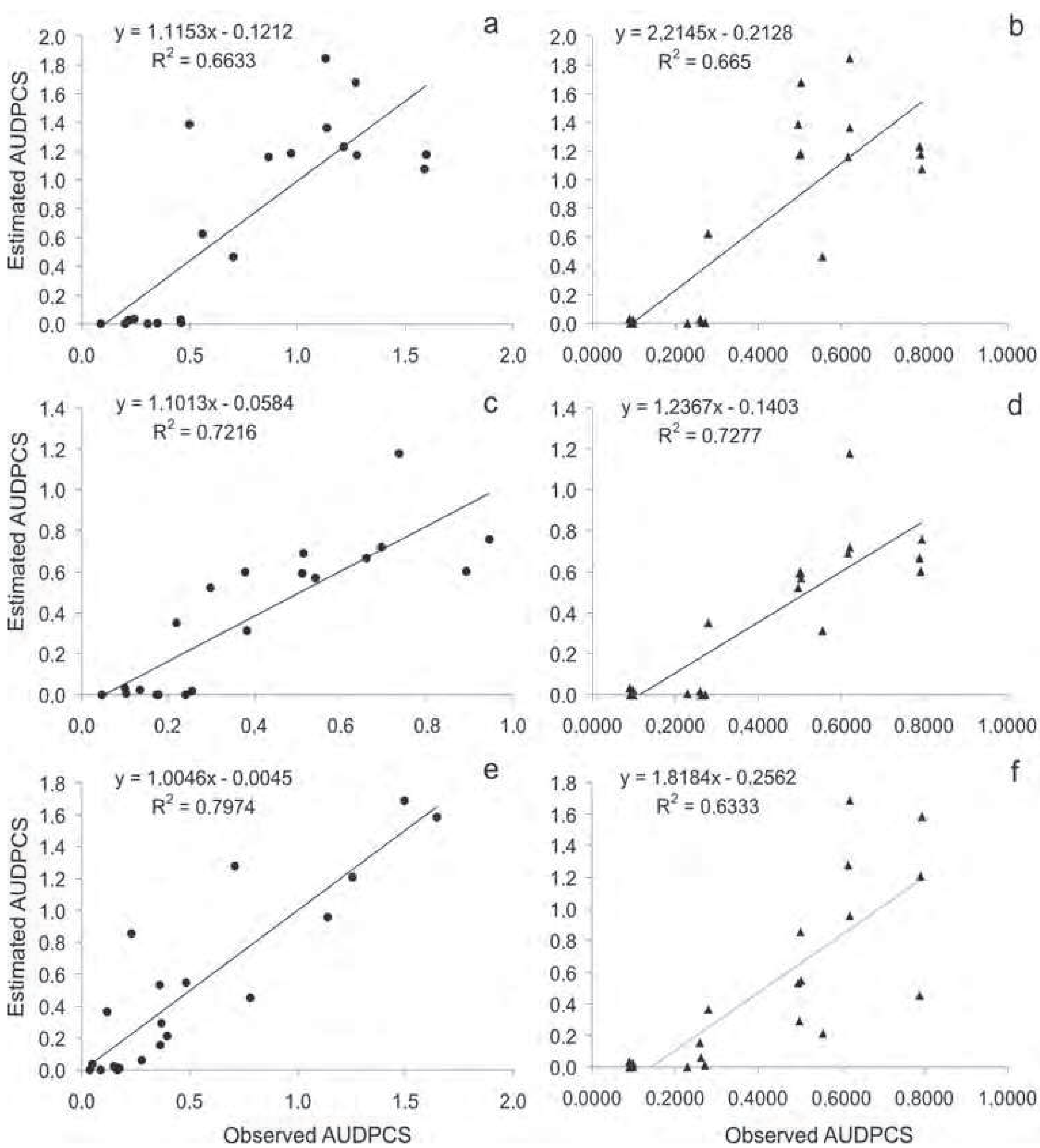

Fig. 8. Linear relationship between observed and predicted values of the area under the curve of severity progress (AUDPCS) of soybean rust through models of nonlinear regression (a, c, e) and FLS (b , d, f) on the cultivar Conquista (a, b), Savana (c, d) and Suprema (e, f) cultivars.

Method	AUDPCI observed			AUDPCS observed		
	Conquista	Savana	Suprema	Conquista	Savana	Suprema
RNL	0.8962*	0.85583*	0.91599*	0.81441*	0.84947*	0.89295*
FLS	0.92195*	0.8603*	0.93697*	0.81548*	0.85303*	0.7958*

*1% significant.

Table 2. Pearson correlation coefficients (r) for the observed values of the area under the curve of incidence progress (AUDPCI) and severity (AUDPCS) of soybean rust and the models estimated by nonlinear regression (RNL) and fuzzy logic system (FLS)

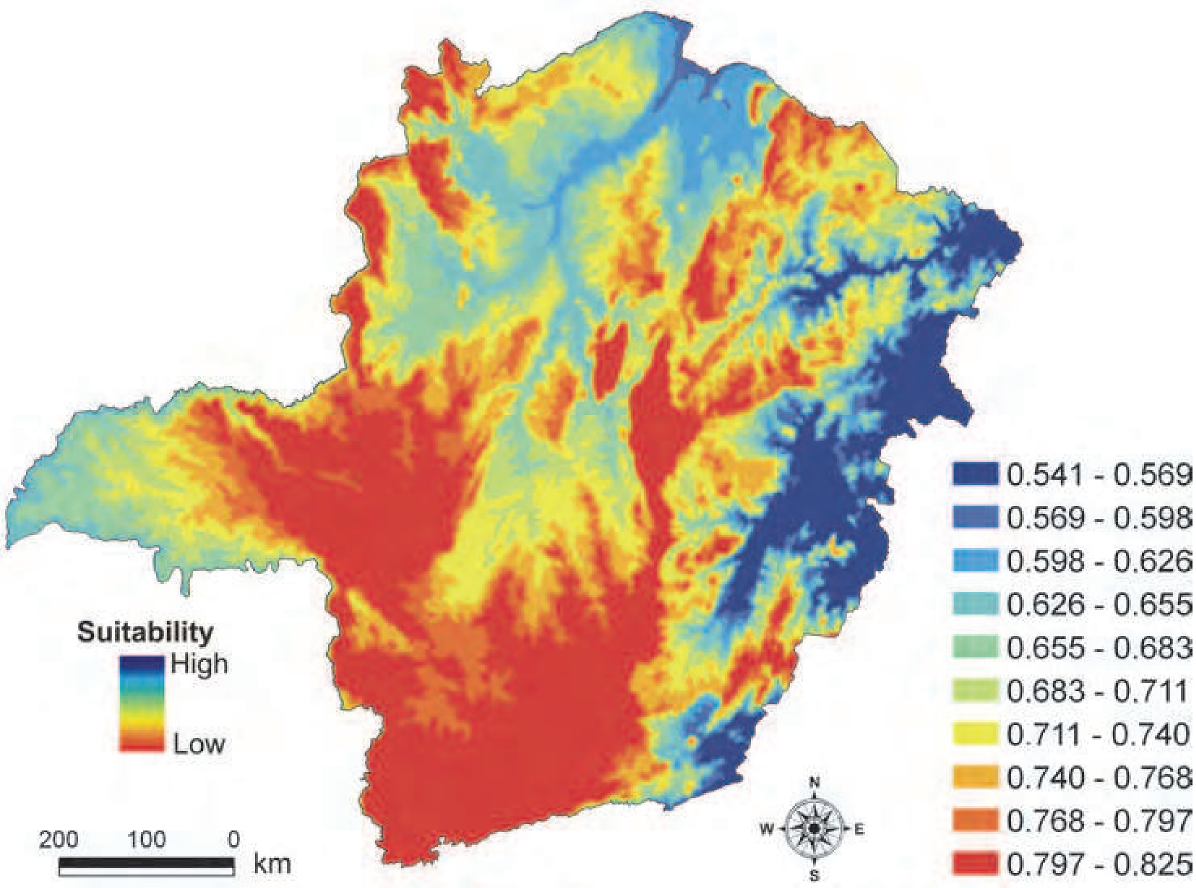

Fig. 9. Intensity of soybean rust in Minas Gerais, estimated by FLS, for the period of 1961 to 1990, based on observations of average monthly temperature in January of 39 weather INMET stations, with the leaf wetness period fixed at 12 hours, using altitude, latitude and longitude as covariates.

	Ordinary kriging		Co-kriging	
Variable	RMSE	Standard error	RMSE	Standard error
Rust intensity	0.07526	0.07746	0.05497	0.03604

Table 3. Coefficients of the estimate quality of the methods of ordinary kriging and co-kriging.

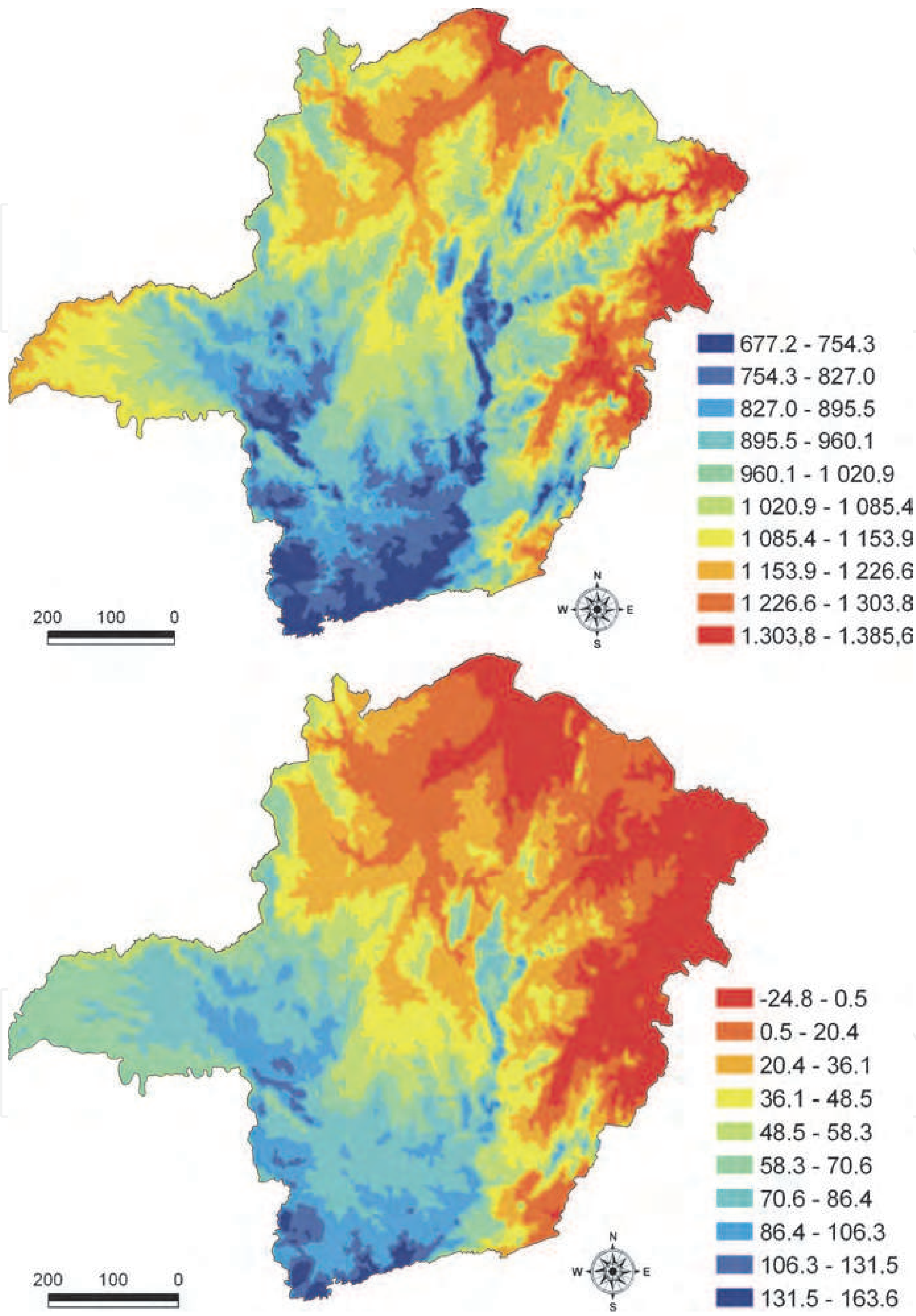

Fig. 10. Annual potential evapotranspiration (ETp) estimated by Thornthwaite (TW) (a) and annual moisture index (Iu) estimated by TW (b) in Minas Gerais, based on of 39 meteorological INMET stations, using co-kriging with altitude, latitude and longitude covariates.

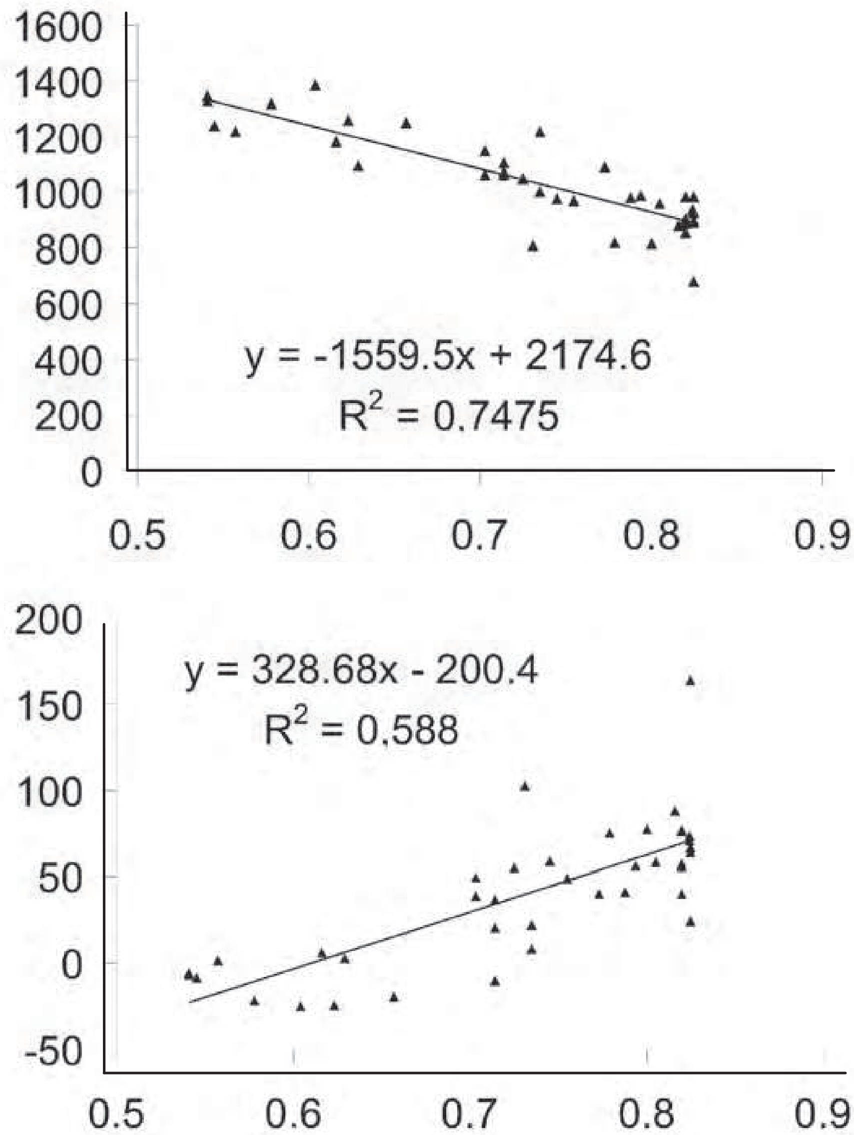

Fig. 11. Linear relationship between annual potential evapotranspiration (ETp) (Y axis) estimated by Thornthwaite (TW) (top) and annual moisture index (Iu) (Y axis) estimated by TW (down), with the potential intensity of soybean rust estimated by FLS (X axis), for the observations of monthly average temperature in January, at 39 INMET weather stations in Minas Gerais and surrounding states, with the leaf wetness period fixed at 12 hours.

Similarly, Morales & Jones (2004) used GIS to study the ecology and epidemiology of whitefly (*Bemisia tabaci* Gennadius 1889), transmitting geminiviruses in tropical crops in Latin America, at 304 georeferenced locations, where the whitefly and geminiviruses have caused significant damage. For this, it was developed a mathematical model including two climatic variables, temperature and precipitation, to map the probability of occurrence of favorable areas for pests. Later, using the Köeppen climatic classification, it was possible to verify that 55% of the localities affected by geminiviruses were located in the tropical wet-dry, 22% in humid-dry tropical regions, subtropical and local remnants of humid equatorial climates, with frequent coastal winds. According to the authors, based on the results, it was

possible to understand the epidemic of whiteflies and geminiviruses, in order to assist the sustainable integrated pest management and disease in the studied regions. Vale et al. (2004) also reported the influence of climate on the inoculum survival, both between crop seasons and within the crop season. According to the authors, the survival of inoculum between cropping seasons is lower in temperate regions with arid or semi-dry summer, because under these characteristics, there is destruction of the survival structures, limiting the pathogen infection. Once inside the growing season for disease caused by polycyclic fungi and bacteria, the inoculum survival was higher in temperate regions, with low temperatures, low solar radiation and longer duration of leaf wetness. According to these authors, the temperature interfered with plant physiological processes, such as evapotranspiration, however, according to the results of this study, this variable may also be related to processes of infection, colonization, sporulation and survival of pathogens.
In this context, it became possible to develop, validate and implement a FLS for soybean rust, based on temperature and leaf wetness, for the cultivars Conquista, Savana and Suprema. Other important features on the FLS may be related to the system's simplicity, ease of implementing in field conditions, and the flexibility of the used method to incorporate other variables.

4. Conclusion

It was possible to develop, validate and implement a fuzzy logic system to estimate the monocyclic process of soybean rust, regarding Conquista, Savana and Suprema cultivars, based on temperature, leaf wetness and area under disease progress curve. The co-kriging method was more accurate and precise than the ordinary kriging method for mapping rust intensity.
FLS was better applied then non linear regression models to estimate the potential disease spatial progress.
The moisture index and potential evapotranspiration of Thornthwaite were significantly correlated with the estimates of the soybean rust intensity.
Leaf wetness up to 12 hours and temperatures around 20 °C, determined higher rust intensity. Temperatures above 30 ºC and 15 ºC as well as leaf wetness below 6 hours, reduced the rust intensity.

5. References

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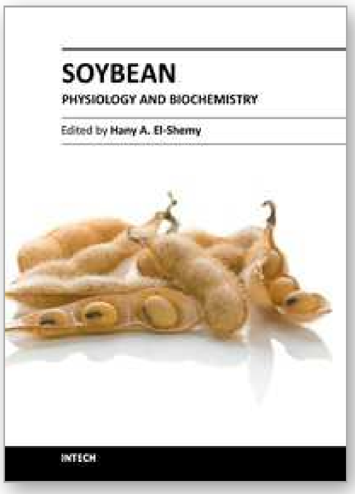

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Worldwide, soybean seed proteins represent a major source of amino acids for human and animal nutrition. Soybean seeds are an important and economical source of protein in the diet of many developed and developing countries. Soy is a complete protein and soyfoods are rich in vitamins and minerals.Soybean protein provides all the essential amino acids in the amounts needed for human health. Recent research suggests that soy may also lower risk of prostate, colon and breast cancers as well as osteoporosis and other bone health problems and alleviate hot flashes associated with menopause. This volume is expected to be useful for student, researchers and public who are interested in soybean.