Original Article

ASIAN SOYBEAN RUST: MODELING THE IMPACT ON SOYBEAN GRAIN YIELD IN THE TRIÂNGULO MINEIRO/ALTO PARANAÍBA REGION, MINAS GERAIS, BRAZIL

FERRUGEM ASIÁTICA DA SOJA: MODELAGEM DO IMPACTO NA PRODUTIVIDADE DA SOJA NA REGIÃO DO TRIÂNGULO MINEIRO/ALTO PARANAÍBA, MINAS GERAIS, BRASIL

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ABSTRACT: Understanding the impact of Asian soybean rust on soybean yield is of great importance in the crop simulation model for this crop become it is possible to predict yield using different sowing dates and growth conditions. The goal of this study were to evaluate the performance of two soybean cultivars in Triângulo Mineiro/Alto Paranaíba, MG, Brazil and the effects of soybean rust on the yield of these cultivars using the CSM-CROPGRO Soybean model. Two soybean cultivars "NK 7074" (early) and "UFUS-Impacta" (medium late), which differ in their development cycles, were growing in Uberaba city during the 2009/2010 growing season. The validation for cultivar "UFUS-Impacta" was conducted comparing the measured and simulated yield data considering three different sowing dates in the "Uberlândia" city during the 2002/2003 growing season. Daily meteorological data obtained from six meteorological stations of the National Institute of Meteorology (INMET). To determine the performance of the soybean cultivars and the effect of soybean rust on yield, three different scenarios were used: no occurrence of rust (NOR) and occurrence of rust with inoculum concentrations of U5.000 and U10.000 urediniospores/mL. For all environments studied, the early cultivar had the best performance than the medium late cultivar. Soybean rust had the most effect on yield for the U10.000 scenario than for the U5.000 scenario. The best soybean performance occurred for "Araxá" and "Uberaba" cities. The South-Southeast area of the "Triângulo Mineiro/Alto Paranaíba" region was the most sensitive to the effect of rust on yield compared to the North region.

KEYWORDS: *Glycine max*. modeling. *Phakopsora pachyrhizi*.

INTRODUCTION

Soybean (*Glycine max* l. Merrill) is considered to be the largest commercial crop in Brazil, as it is the most important source of plant protein and a fundamental component of animal feed, with increasing importance in the human diet (BALARDIN, 2002).

The national production of soybean for the 2010/2011 harvest, estimated at 75.31 million tons, was similar to the average of recent years. Minas Gerais state ranks fifth in the national production of soybeans, with the 2009/2010 harvest yielding approximately 3 million tons and an average yield of 2,965 kg ha^{-1}. The counties that invest the most in this crop are concentrated in the "Triângulo Mineiro" and "Alto Paranaíba" regions (CONAB, 2011).

Among the diseases that occur in the soybean crop, Asian rust, caused by *Phakopsora pachyrhizi* Sydow & Sydow fungus, is considered to be the most destructive. In the Americas, this disease was recorded for the first time as an epidemic in Paraguay in March 2001 and two

Received: 05/07/12
Accepted: 05/12/12

months later in Brazil. Since then, its expansion through soybean plantations was swift, and the losses are estimated at 8.5 million tons of grain in the period between 2001 and 2004. During the 2001/2002 season, soybean rust spread throughout the south and part of the mid-west of Brazil and in “Triângulo Mineiro”, in the municipality of Uberlândia, Minas Gerais state accounts for approximately 60% of the soybean production in Brazil (YORINORI et al., 2002).

Since the first detection, outbreaks have occurred (YORINORI, 1997), and the disease is nowadays rapidly spread to the main producing regions by the wind. Compared to areas treated with fungicides, reductions in yield near 70% may be observed when treatment is not undertaken. Under optimum conditions for the fungus development, the expected loss is above 80% (EMBRAPA, 2005).

The main climatic variables determining the occurrence of Asian Soybean Rust are leaf wetness duration, the average temperature during the wet period and relative humidity. These variables influence the progress of disease by directly affecting the infection process of *P. pachyrhizi* (REIS et al., 2004). The epidemiological knowledge using both controlled and natural conditions to elucidate the factors affecting the progression of the disease has been fundamental for modeling studies of epidemics (DEL PONTE, 2006).

According to Del Ponte (2008), basic studies and epidemiological modeling of rust for short-term and long-term predictions has had some breakthrough in Brazil with regard to the monitoring of disease patterns for each harvest. This author highlights three essential factors to be considered in defining these patterns: i) the presence of the inoculum in a region; ii) climate variability; and iii) disease control with fungicides. The importance of these combined factors has become evident because epidemics are controlled by proper management practices and/or conditions (climate typically) unfavorable for the spread of the disease.

Soybean rust reduces leaf area through reduction in nonlesion green leaf area and leaf loss due to accelerated leaf defoliation, consequently, induced yield loss and cause reduction in canopy green leaf area due to Soybean Rust lesions. However, to start the reduction in dry matter accumulation per unit absorbed radiation by the nonlesion green leaf area, and reduction in harvest index. The response of harvest index was attributable to reduced seed set and seed mass resulting likely from Soybean Rust induced reductions in rate of dry matter accumulation. Therefore, leaflet drop, which is first observed at the bottom of the canopy will continue upward, and eventually lead to complete defoliation in plants with high levels of disease development severity (KUMUDINI et al., 2008).

Therefore, the goal of this study is to evaluate the performance of two soybean cultivars in Triângulo Mineiro/Alto Paranaíba, MG, Brazil and the effects of soybean rust on the yield of these cultivars using the CSM-CROPGRO Soybean model.

MATERIAL AND METHODS

Calibration and Validation of the CSM-CROPGRO-Soybean Model

In this study, two soybean cultivars, NK 7074 (early) and UFUS-Impacta (medium late), were used. The observed data for the calibration of the model were obtained in a field experiment conducted at Uberaba-MG, -19° 21' 34.7" latitude, -47° 50' 40.5" longitude and 978 m above mean sea level (AMSL). The experimental design was in randomized blocks, with four repetitions. The sowing date, seeding density and stand were 11/20/2009, 20 seeds per linear meter and 18 plants per linear meter. The number and length of rows was 12 m^{-2}, with a spacing of 0.5 m. The soil in the experimental area was classified as Dark Red-Yellow distrophic Latosol.

For model phenological coefficients calibration it was used as observed data the sowing, emergence, flowering and physiological maturity dates. For yield related components it was used observed yield.

The validation of the genetic coefficients estimated to cultivate UFUS-Impacta was conducted comparing the observed yield data described by Hamawaki et al. (2005) and simulated yield data considering three different sowing dates of 10/18/2002, 11/1/2002 and 12/10/2002. In this case, the climatic data were used for the 2002/2003 growing seasons and soil characteristics were that of the municipality of Uberlândia.

Meteorological and Soil Database

The evaluation is carried out by taking account observed daily minimum and maximum average air temperatures (°C), the precipitation (mm) and the number of hours of insolation (n) is used for the calculation of the solar radiation (MJ day^{-1} m^{-2}), as obtained from six meteorological stations of the National Institute of Meteorology (INMET) and described in Table 1. The Triângulo Mineiro/Alto Paranaíba region is located in the Southeast part of Brazil (Figure 1).

Table 1. Weather Stations of INMET using in this study

Code	Weather Station	Longitude (°)	Latitude (°)*	Elevation (m)**	Years
83514	Capinópolis	-49.55	-18.72	620	1991-2005
83521	Ituiutaba	-49.52	-18.97	560	1991-2005
83531	Patos de Minas	-46.43	-18.52	940	1991-2005
83574	Frutal	-48.93	-20.03	543	1992-2005
83577	Uberaba	-47.95	-19.73	737	1989-2010
83579	Araxá	-46.93	-19.6	1023	1992-2008

* Negative: City situated in the southern hemisphere; ** Elevation in meters.

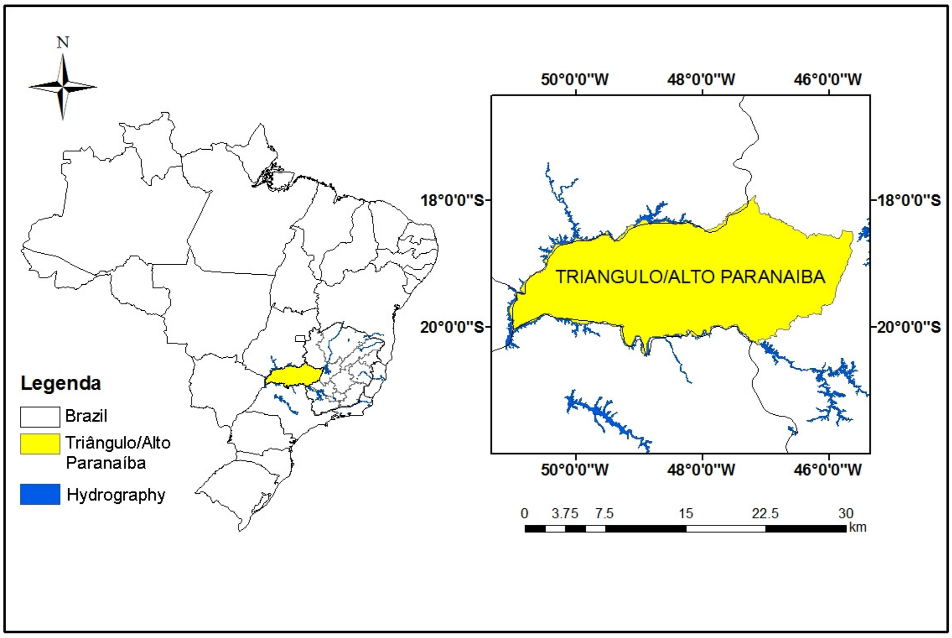


Figure 1. Region of study: the Triângulo Mineiro/Alto Paranaíba, Minas Gerais State, Brazil.

The soil data used is based on RADAM BRAZIL project (BRAZIL, 1986), applying the soil more representative of the region closest to the weather station. To estimate the values of the lower limit, drained upper limit and saturation of the soil, the methodology proposed by Tomasella et al. (2000) was employed. The soil profile and its physical-hydrics characteristics are described in Table 2.

Yield simulation of early and medium-late cultivars

To determine the performance of the soybean cultivars and the effect of Asian soybean rust, six sowing dates were used: 10/15; 11/1; 11/15; 1/12; 12/15 and 12/30. The simulations began two months before the sowing date to stabilize the water balance.

Only the estimated yield predicted by the model was used to determine the performance of the soybean cultivars and the effect of Asian rust in the region. Three different scenarios were considered: (i) no occurrence of rust (NOR); (ii) occurrence of rust with an inoculum concentration in urediniospores/mL of 5.000 (U5.000) and (iii) occurrence of rust with inoculum concentration of 10.000 urediniospores/mL (U10.000).

The yield simulation of early and medium-late cultivars in the Triângulo Mineiro/Alto Paranaíba region was done considering the integration between CSM-CROPGRO: Soybean and the soybean rust model using the U5.000 and U10.000 scenarios.

The coupled models have the capacity to dynamically represent the progress of Asian soybean rust and its influence on yield. The rust model is primarily based on the leaf wetness duration (LWD). To estimate LWD, the daily maximum and minimum temperatures of the historical weather data for the six cities used in the present study were converted into hourly data using the algorithm proposed by Parton and Logan (1981).

Table 2. Physical characteristics of the soil and soil water used in the experimental area of Triângulo Mineiro/Alto Paranaíba Minas Gerais State.

City	Depth (cm)		Silt (%)	Clay (%)	Sand (%)	Saturation (cm3/cm3)	Upper Limit (cm3/cm3)	Lower limit (cm3/cm3)	Global density (g/cm3)
	Bottom	Upper							
Capinópolis	0	13	26	23	51	0.555	0.363	0.179	1.3
	13	30	29	17	54	0.515	0.336	0.151	1.4
	30	60	29	17	54	0.515	0.336	0.151	1.4
Ituiutaba	0	15	5	13	82	0.422	0.191	0.094	1.6
	15	40	5	12	83	0.418	0.187	0.087	1.6
	40	65	4	12	84	0.413	0.181	0.086	1.6
	65	95	5	14	81	0.420	0.193	0.094	1.6
Patos de Minas	0	6	44	50	6	0.637	0.508	0.278	1.1
	6	18	38	57	5	0.596	0.475	0.297	1.2
	18	28	38	60	2	0.588	0.474	0.304	1.3
	28	98	32	64	4	0.564	0.450	0.313	1.3
Frutal	0	14	12	65	23	0.574	0.416	0.294	1.2
	14	34	11	65	24	0.568	0.416	0.294	1.2
	34	56	15	63	22	0.556	0.412	0.294	1.3
	56	90	11	69	20	0.569	0.415	0.299	1.2
Uberaba	0	10	11.3	11.1	77.6	0.448	0.218	0.104	1.5
	10	25	11.9	13.1	75	0.448	0.225	0.112	1.6
	25	55	10.9	14.6	74.5	0.439	0.227	0.116	1.6
	55	110	13	15.5	71.5	0.444	0.239	0.124	1.6
Araxá	0	10	12	16	72	0.455	0.241	0.126	1.4
	10	36	9	17	74	0.425	0.223	0.123	1.6
	36	84	6	24	70	0.437	0.241	0.143	1.6
	84	162	6	29	65	0.477	0.265	0.161	1.6

In order to analyze the rust effect on soybean yield 5 (five) variables have been utilized to integration the models: (1) DOY (day of the current simulation) in the Julian format; (2) AREALF, the remaining healthy leaf area in cm^2; (3) DYNAMIC, the state of the simulator; (4) DISLA (the variable used for the allocation of total diseased leaf area) and (5) WLIDOT (an integration variable used to assign the damage caused by pests or cold damage to the leaf mass). A detailed model description has been provided by Rodrigues et al. (2012).

To evaluate the performance of the two cultivars for the three different scenarios (NOR, U5.000 and U10.000) were used the probability of exceeding, which is defined by equation 1

$$E(x) = 1 - F(x), F(x) = P(X \leq x), (1)$$

where E (x) is the probability of exceeding (%), F (x) stands for the cumulative distribution function (%). P (X ≤ x) is the probability that the variable X is less than or equal to x in which x represents the simulated yield in kg ha^{-1}.

For NOR scenario the probability of exceeding as well as the mean variance analysis were applied for each local and sowing date. For the rust scenarios (U5.000 and U10.000) it was applied only the probability of exceeding considering all locations and sowing dates together and compared with NOR scenario with the objective to demonstrate the impact of rust on simulated yield.

To analyze the effect of Asian rust on the yield of the soybean cultivars, the probability of exceeding and the regional maps of yield were considered. For the calculation of the probability of exceeding, was used the simulated yield obtained for the six sowing dates and the six locations for each of the scenarios, NOR, U5.000 and U10.000. The maps of yield for the NOR, U5.000 and U10.000 scenarios were generated using the simulated yield average obtained for each location and their respective sowing dates.

To improve the visualization of the spatial representation, the simulated yield averages were grouped into 10 larger, ordered classes of higher to lower yield: > 5000, 4500, 3500, 4000, 3000, 2000, 2500, 1500, 1000 and < 500 kg ha^{-1}. It should be noted that by evaluating different sowing dates the influence of climate variability in leading, to soybean rust incidence may be analyzed.

RESULTS AND DISCUSSION

Characterization of climate conditions in the Triângulo Mineiro/Alto Paranaíba region

Turning to temperature, it is clear that the topography/altitude plays the dominant role. For instance, Araxá (Ituiutaba) is located at 973 (605) (AMSL) and to define thermal characteristics. Indeed, the short distance between both municipalities demonstrated the highly significant effect of topography because the seasonal amplitude does change considerably between these cities (Figure 2).

Higher temperature is associated with higher rate of evapotranspiration and therefore with higher atmospheric demand of water. In this sense, depending on the atmospheric demand of water the crop system may experience hydrological stress even during the rainy season (Figure 2).

The Triângulo Mineiro/Alto Paranaíba region is characterized by well defined seasonal cycle in both precipitation and temperature. The onset of the rainy season is October and extends until March/April. Among the Triângulo Mineiro/Alto Paranaíba municipalities, highest precipitation by up to 1300 mm/year is observed in Ituiutaba, Uberaba and Araxá. However, very low precipitation is noted in the dry season between May and September. Therefore, crop production during this season is affected by water shortage and irrigated production is the only way of succeeding. It should be noted that dry-spells may also occur in the rainy season (Figure 2).

Evaluation of Calibration and Validation

The early and medium-late soybean cultivars showed differences in the adjusted genetic coefficients, mainly related to phenology, such as the length of the time between seedling emergence and the emergence of the first flower and between the physiological maturity and seedling emergence. This may demonstrate the sensitivity of the CSM-CROPGRO: Soybean model with regard to the development of the cultivars. The values of model coefficients estimated by the CSM CROPGRO Soybean model for both cultivars are presented in Table 3.

For the analysis of the grain yield without the presence of the rust, the CSM CROPGRO-Soybean model estimated, reasonably, a significant income for soybean cultivar NK 7074, which resulted in a difference of 90 kg ha^{-1} from the observed (3474 kg ha^{-1}) and simulated (3564 kg ha^{-1}) values for the 2009/2010 growing season. However, for UFUS-Impacta, the difference recorded was 338 kg ha^{-1} between the observed (4098 kg ha^{-1}) and simulated (3760 kg ha^{-1}) values (Table 4).

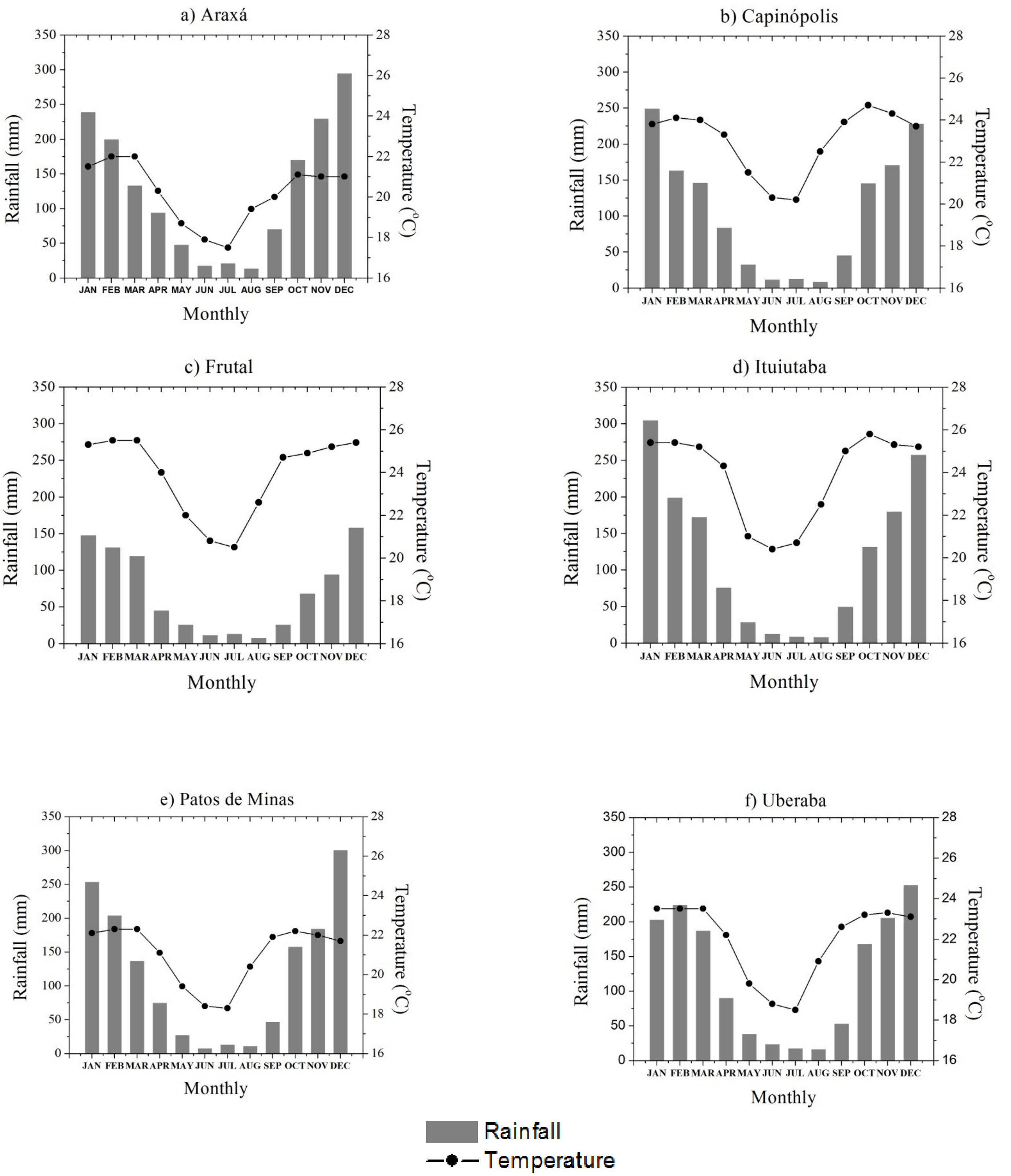


Figure 2. Climatology of precipitation and air temperature in the Triângulo Mineiro/Alto Paranaíba region between 1961-1990 (INMET)

Table 3. Genetic coefficients used in the CSM CROPGRO-Soybean model calibrated for the early and late maturity cultivars.

Genetic coefficients	Units	Cultivars	
		NK 7074	UFUS-Impacta
CSDL (1)	Hours	12.15	12.02
PPSEN (2)	1/hour	0.343	0.384
EM-FL (3)	Photothermal Days	23.75	28.20
FL-SH (4)	Photothermal Days	10.00	10.00
FL-SD (5)	Photothermal Days	19.85	14.90
SD-PM (6)	Photothermal Days	34.15	29.87
FL-LF (7)	Photothermal Days	19.00	25.00
LFMAX (8)	Rate	1.185	1.390
SLVAR (9)	cm^2	320.4	333.8
SIZLF (10)	cm^2	161.5	223.6
XFRT (11)	Proportion	1.000	1.000
WTPSD (12)	Grass	0.156	0.170
SFDUR (13)	Photothermal Days	24.17	21.06
SDPDV (14)	Photothermal Days	1.859	2.192
PODUR (15)	Photothermal Days	10.00	10.00

Where: (1)CSDL: Critical Short Day Length below which reproductive development progresses with no daylength effect (for short day plants) (hour); (2) PPSEN: Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour); (3) EM-FL: Time between plant emergence and flower appearance (R1) (photothermal days); (4) FL-SH: Time between first flower and first pod (R3) (photothermal days); (5) FL-SD: Time between first flower and first seed (R5) (photothermal days); (6) SD-PM: Time between first seed (R5) and physiological maturity (R7) (photothermal days); (7) FL-LF: Time between first flower (R1) and end of leaf expansion (photothermal days); (8) LFMAX: Maximum leaf photosynthesis rate at 30^{o}C, 350 vpm CO2, and high light (mg CO2/m2-s); (9) SLAVR: Specific leaf area of cultivar under standard growth conditions (cm2/g); (10) SIZLF: Maximum size of full leaf (three leaflets) (cm2); (11) XFRT: Maximum fraction of daily growth that is partitioned to seed + shell; (12) WTPSD: Maximum weight per seed (g); (13) SFDUR: Seed filling duration for pod cohort at standard growth conditions (photothermal days); (14) SDPDV: Average seed per pod under standard growing conditions; (15) PODU: Time required for cultivar to reach final pod load under optimal conditions (photothermal days).

Table 4. Average measured and simulated with CSM CROPGRO-Soybean for NK 7074 and UFUS-Impacta cultivars in 2009/2010 growing seasons, in Uberaba, MG.

Calibration 2009/2010					
Cultivars	Variables	Simulated	Measured	Difference	PD (%)
NK 7074	Flowering (days)	45	50	5	****
	Physiological maturity (days)	125	125	0	****
	Yield (kg ha^{-1})	3564	3474	91	2.5
UFUS-Impacta	Flowering (days)	60	60	0	****
	Physiological maturity (days)	133	132	1	****
	Yield (kg ha^{-1})	3760	4098	338	-8.24

Utilizing the CSM CROPGRO: Soybean model to simulate the development of soybean cultivars CD 202, CD 204, CD 206 and CD 210 to the region of Palotina, PR, Dallacort et al. (2005) also noted a satisfactory adjustment between the dates of flowering and physiological maturity when comparing the observations and simulation. The CSM CROPGRO: Soybean model also accurately estimated the yield in the validation of UFUS-Impacta (Table 5).

Table 5. Average values of the yield measured with the CSM-CROPGRO: Soybean cultivars for UFUS-Impacta in 2007/2008 growing seasons in the Uberlândia, MG according to Hamawaki et al. (2005)

Validation 2002/2003						
Cultivar	City	Variable	Simulated	Measured	PD (%)	Difference
UFUS-Impacta	Uberlândia	Yield (kg ha^{-1})	3572	4014	11	442

Performance of early and medium-late cultivars in Triângulo Mineiro/Alto Paranaíba for the NOR scenario

Evaluations conducted here show that the early cultivar had a better performance than medium late cultivar (Fig.3). For Araxá and Patos de Minas the best strategy for the early cultivar is to sow as early as possible (Fig. 3a and e). In both locations, the highest mean simulated yield was obtained at 15/oct sowing date (Fig. 4). For Patos de Minas it is more evident because the simulated yield variance is lower than Araxá. Also, in both locations the mean accumulated precipitation is higher at this sowing date (Fig. 5). For Capinópolis the best strategy is sowing at 01/nov (Fig. 3b). This sowing date had the highest mean simulated yield as well as the lowest variance (Fig. 4b). This seems to be associated with lower variability in the accumulated precipitation (Fig. 5). For Frutal and Uberaba, both sowing date 15/oct and 01/nov had similar profile for the probability of exceeding (Fig. 3c) as well as the same mean simulated yield (Fig. 4c). Moreover, 15/Oct showed the lowest variance for the mean simulated yield. For Ituiutaba the sowing date 01/nov presented the highest mean simulated yield and 01/dec the lowest variance (Fig. 3d and 4d). Based on investigations insofar soybean is concerned Araxá and Uberaba, are the most suitable locations. In these locations it was possible to get the highest yields with the lowest variability (low variance, Fig. 4a and f).

For the different sowing dates studied, October 15, November 1 and November 15 were notable for the NK 7074 and UFUS-Impacta cultivars. The city of Patos de Minas gained an increase in yield for the sowing date in October and the city of Uberaba for November, with a seeding of 5300 kg ha^{-1} for NK 7074. Similar results were found for these same cities for the second cultivar, with seeding values of 4509 kg ha^{-1}. It is noted that greater yields were found for all of the sowing dates in Uberaba for both cultivars. The results showed that for those dates, the farmer it is sowing date more early chance the producer must obtain increased grain yield (Figure 3). The preferred time of sowing is one for which the risk of yield loss due to water deficiency has a lower probability of occurrence (BARNI; MATZENAUER, 2000).

In general, the cities of Araxá and Uberaba showed a smaller variance in yield for the six sowing dates for the early cultivars (NK 7074) and (UFUS-Impacta). However the towns of Frutal, Capinópolis and Ituiutaba showed greater variance in yield (Figure 4).

This yield variability is associated with different amounts of precipitation in the six cities studied. Ituiutaba, Frutal and Capinópolis had smaller amount accumulated of precipitation on the different sowing dates, which affect both the number and size of the pods and the quantity and weight of the grains. The precipitation rate tends to decrease after the month of April, marking the beginning of the dry season in the region of Triângulo Mineiro/Alto Paranaíba. Thus, less water is available in the soil at a later sowing date, resulting in a lower income. In contrast, the cities of Uberaba and Araxá recorded the greatest amount of precipitation during the soybean growth cycle for the different sowing dates, with consequently higher incomes, proving the sensitivity of the associated model to the environmental conditions, particularly the water availability in the soil (Figure 5).

Accordingly, the farmer should consider the factors of a combination of phenology and the distribution of climatic elements in the region of production. When choosing an earlier sowing date (e.g., October and November), the risk of failure may decrease due to the lower risk of a water deficit during the most critical phenological stages, generating a crop with a higher income. In this sense, the NK 7074 and UFUS-Impacta cultivars showed different these cycles due to the changes in climate, mainly related to the large year-to-year variability and spatial rainfall, generating a large dependence on the time of sowing for each year.

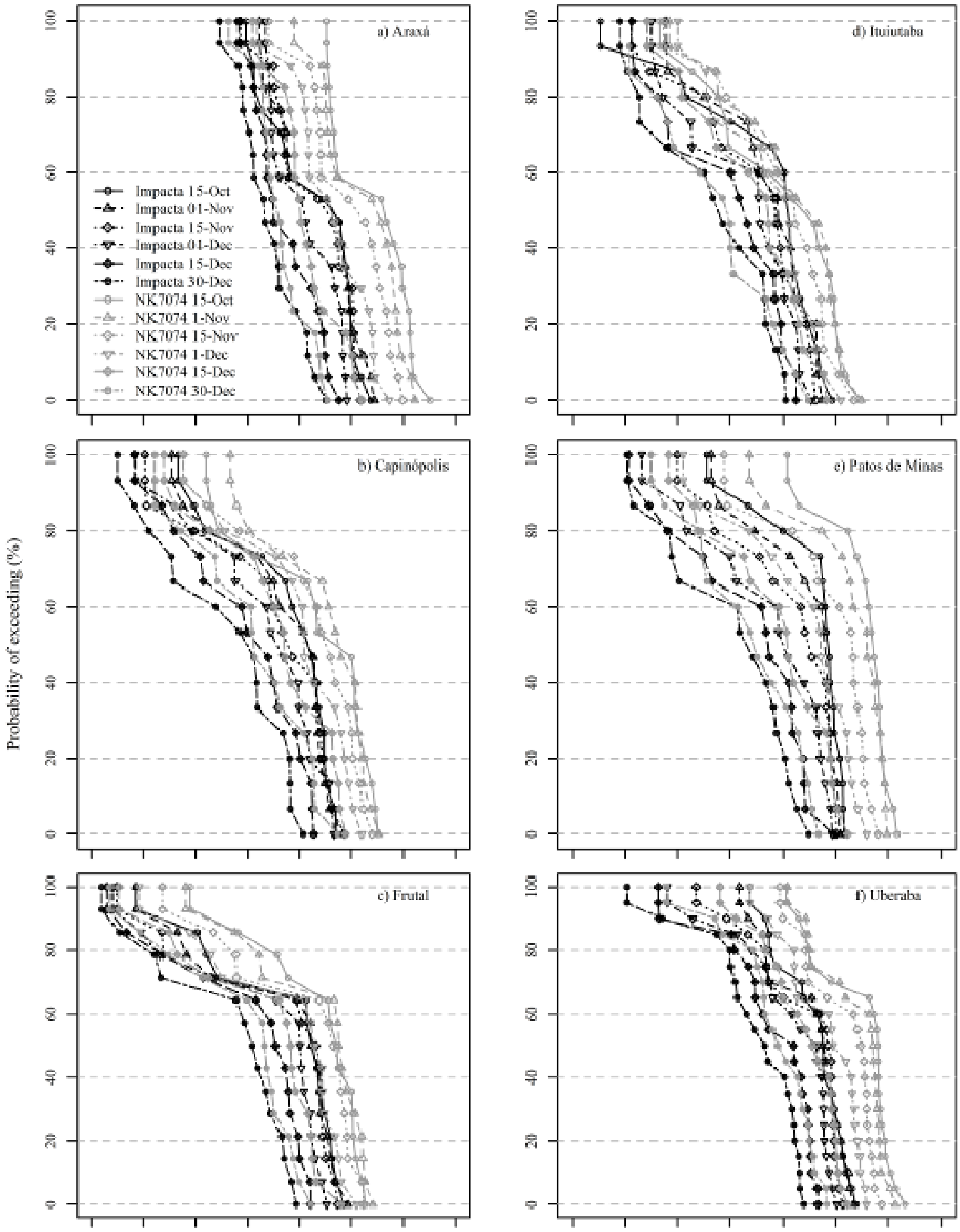


Figure 3. Probability of exceeding of simulated soybean yield, considering NOR scenario for different sowing dates.

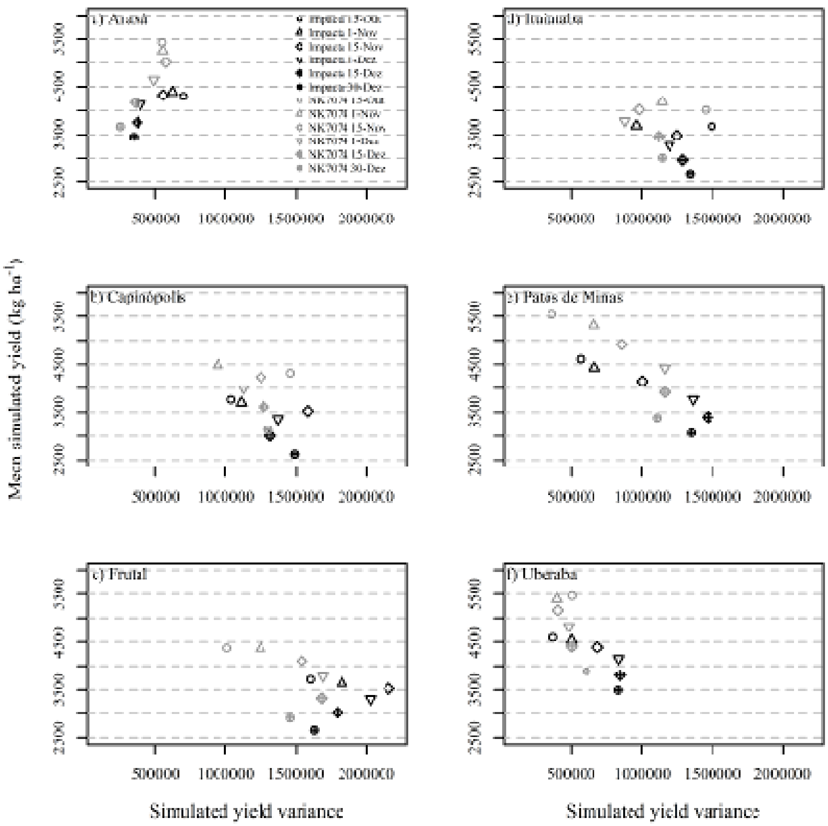


Figure 4. Mean variance for simulated soybean yield, considering NOR scenarios for different sowing dates.

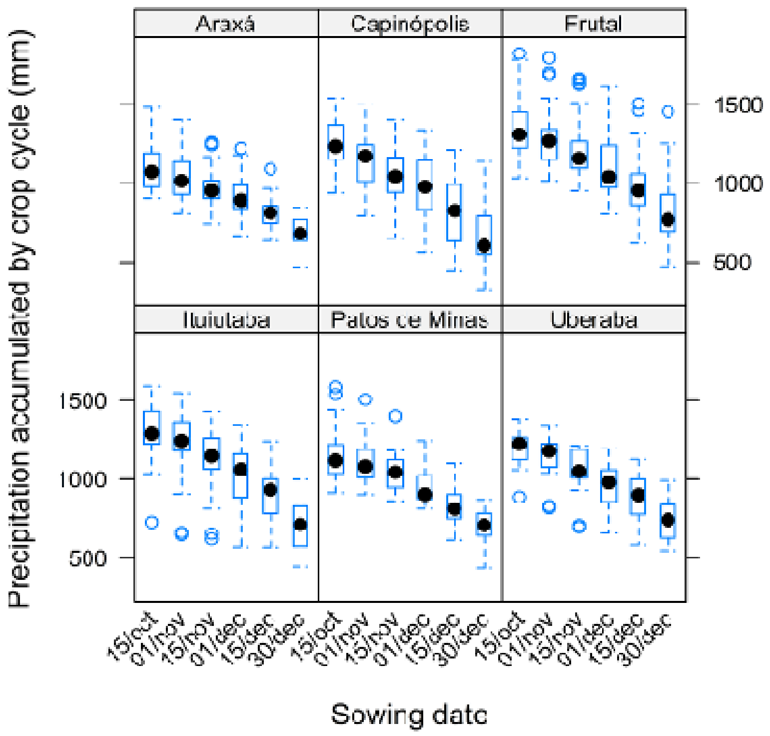


Figure 5. Variability of the accumulated precipitation by crop cycle considering both cultivars for different location and sowing date

According to Pascale & Escales (1975), rainfall is the main factor responsible for the oscillations in yield, followed by thermal accumulation. Although present horizontal resistance and longer cycle is to cultivate UFUS-Impacta at higher elevations (above 1000 m), losses in yield were observed for NK 7074 (interaction cultivar x environment), mainly for the sowing dates of October and November. However, it was observed that cultivating NK 7074 resulted in higher incomes at all times in comparison to UFUS-Impacta, regardless of the effects imposed by rust (Figure 3).

The results discussed here corroborate reports in the literature that the largest grain yields are obtained for sowing dates in the second half of October and November, supporting the trend of increased income for the cultivars at a late October sowing date and sowing dates for early cultivars (URBEN FILHO; SOUZA, 1993; QUEIROZ et al., 1998; COSTA VAL et al., 2003; FARIAS et al., 2007).

Effect of Asian rust on early and medium-late cultivars in U5.000 and U10.000 scenarios in Triângulo Mineiro/Alto Paranaíba

To analyze the effect of rust, it was found that NK 7074 has suffered the greatest effects on scenarios U5.000 and U10.000 in comparison to UFUS-Impacta (Figure 6).

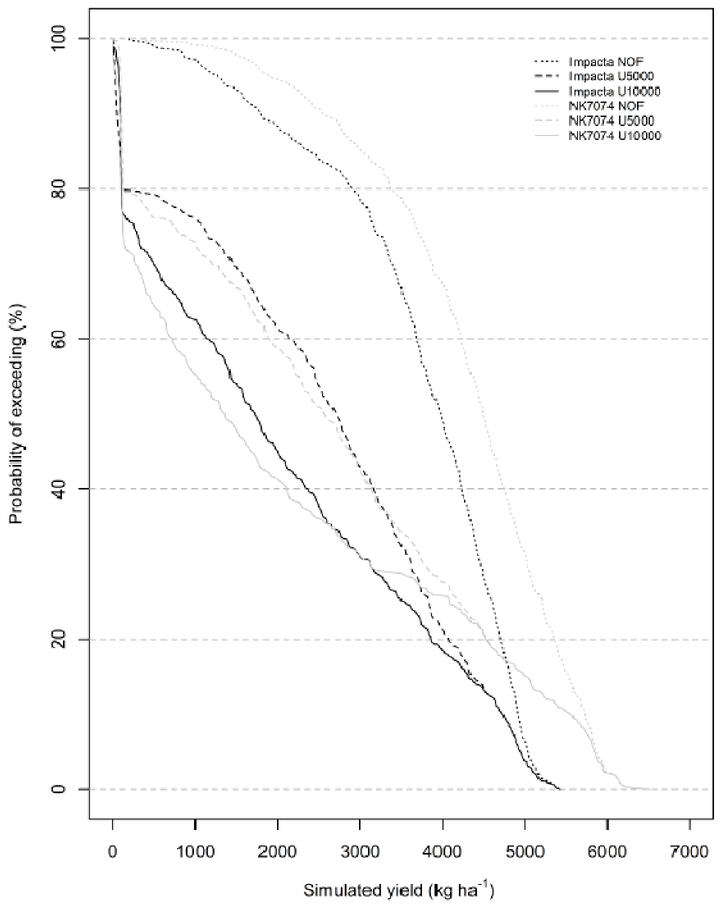
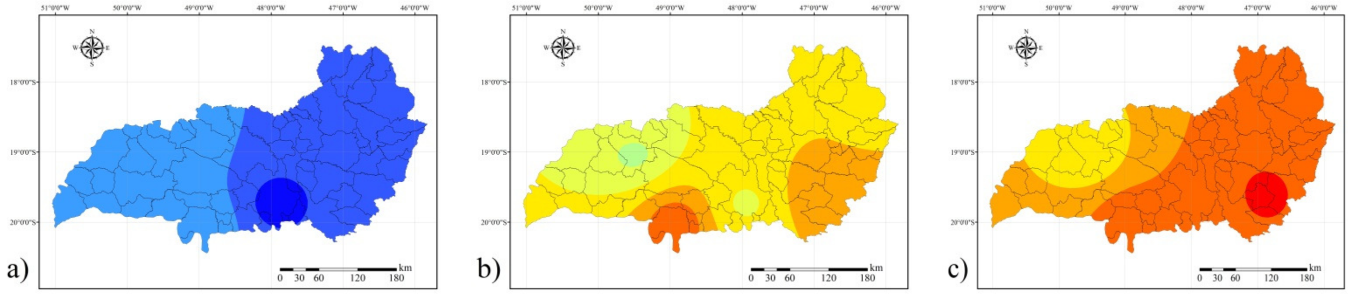


Figure 6. Probability of exceeding for simulated soybean yield, considering allocations and sowing date for scenarios NOR, U5.000 and U10.000

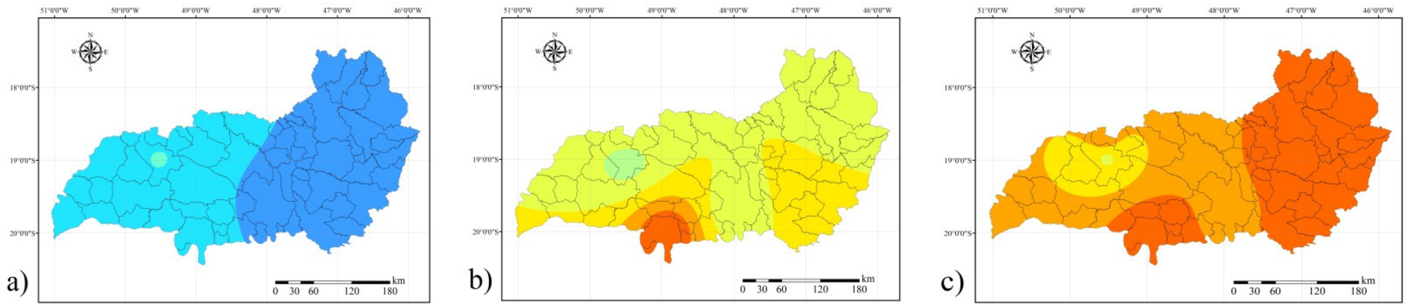
The analysis verified the effect of the rust on different sowing dates, with 15 November being notable for the two cultivars; NK 7074 suffered a larger effect of the rust, with a significant reduction in yield. There was a decreasing trend in the towns of Araxá, Frutal and Patos de Minas, and smaller effects of the rust were observed in the cities of Uberaba, Ituiutaba and Capinópolis. Geographically, it was found that the area south-southeast of Triângulo Mineiro/Alto Paranaíba is more sensitive to the effects of rust versus the North (Figures 7a-c and 8a-c).



Legend - Yield (kg/ha)

- < 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 2,500
- 2,500 - 3,000
- 3,000 - 3,500
- 3,500 - 4,000
- 4,000 - 4,500
- 4,500 - 5,000
- > 5,000

Figure 7. Simulated yield (kg ha^{-1}) in Triângulo Mineiro/Alto Paranaíba, using the NK 7074 cultivar, in the sowing date of november 15th for the scenarios NOR (a), U5.000 (b) e U10.000 (c).



Legend - Yield (kg/ha)

- < 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 2,500
- 2,500 - 3,000
- 3,000 - 3,500
- 3,500 - 4,000
- 4,000 - 4,500
- 4,500 - 5,000
- > 5,000

Figure 8. Simulated yield (kg ha^{-1}) in Triângulo Mineiro/Alto Paranaíba, using the UFUS-Impacta cultivar, in the sowing date of november 15th for the scenarios NOR (a), U5.000 (b) e U10.000 (c).

Using the cultivar UFUS-Impacta, a hybrid between the Cristalina RCH and IAC 100 cultivars, Juliatti et al. (2005) found a partial resistance to *P. pachyrhizi* when compared to the other genotypes studied. By analyzing the epidemiological characteristics of UFUS-Impacta, Silva et al. (2007) found good results, highlighting a partial genetic resistance to *P. pachyrhizi*, and the lower yield for the first season of sowing is explained by the continuation of the cycle in the field.

Thus, the considerations of the above authors reinforces the difference in yield between the NK 7074 and UFUS-Impacta cultivars, with an emphasis on UFUS-Impacta in terms of a lower yield and the effect of rust in the U5.000 and U10.000 scenarios (Figure 6). Additional details regarding the cultivation of UFUS-Impacta can be obtained in Hamawaki et al. (2005).

Accordingly, the greatest loss for the NK 7074 cultivar was associated with the climatic conditions that are favorable to the progression of the rust, particularly when there is more than 90% relative humidity. This situation favors the greatest duration of leaf wetness and, consequently, an increased chance of infection by the fungus.

Rodrigues et al. (2012) showed the late cultivar MG/BR 46 (Conquista) presented the lowest yield considering the effect of Asian rust when the relative humidity was above 90%. The early cultivar M-SOY 6101 was less affected due to rust. When the relative humidity was above 95% and the hours of leaf wetness duration was reduced, rust progress was negatively impacted on the early cultivar as compared to the late one which resulted in great yield increase.

Under brazilian conditions, Alves et al. (2006) conducted experiments with isolated *P. pachyrhizi*, quantifying the effect of the temperature and duration of leaf wetness on the germination of the fungus. The study showed that the optimum range for germination of the pathogen is 15^{o}C to 25^{o}C and that the leaf wetness duration required for infection became longer in adverse temperatures. When there is an availability of free water on the surface of the plant, the infection occurs within six hours of the deposition of urediniospores, and the longer the duration of leaf wetness, the greater the chance of infection (Sinclair and Backman, 1989). Del Ponte et al. (2006) found a high correlation of precipitation (95%) with the severity of rust. Tchanz (1982) in a study in Taiwan suggested that the direct effect of rain on a rust epidemic may be related with the dispersion of the urediniospores within the canopy, which contributes to the rapid progression of the rust.

The months of December and January were the wettest and presented the greatest humidity. When sown in the first two weeks of November, the plants were in the flowering stage and in the reproductive period during the months of December and January, therefore, are more susceptible to infection by *P. pachyrhizi*.

CONCLUSIONS

An advanced sowing date (October) caused an elongation of the cycle that is associated with a higher yield, whereas delayed sowing (December) caused a reduction in the cycle due to a reduction in precipitation.

The sowing date changed the growth of the soybeans. Sowing in November resulted in a greater intensity of rust, followed by higher incomes compared to a sowing date in October. Sowing on November 15 resulted in a higher intensity of rust for the U5.000 and U10.000 scenarios.

The early cycle cultivar presented a greater income but had a significant reduction in yield due to the occurrence of rust. The medium-late cultivar showed a reduced effect of income loss due to rust, as this cultivar has increased tolerance to the disease.

The south-southeast region of Triângulo Mineiro/Alto Paranaíba is more favorable to the occurrence of rust than the northern region.

ACKNOWLEDGMENTS

We are indebted to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES - Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA (Project Number: 32), Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Project Number: 201714/2009-4) and Fundação de Amparo a Pesquisa do Estado de Minas Gerais - FAPEMIG for financial support.

RESUMO: Compreender o impacto da ferrugem asiática na produtividade da soja é de grande importância para os modelos de simulação dessa cultura, pois pode-se prever a produtividade utilizando-se diferentes datas de semeadura e condições de crescimento. O objetivo deste estudo foi analisar a performance de duas cultivares de soja na região do Triângulo Mineiro/Alto Paranaíba, MG, Brasil e os efeitos da ferrugem asiática da soja na produtividade desses cultivares utilizando o modelo CSM-CROPGRO Soybean. Duas cultivares de soja NK 7074 (precoce) e UFUS-Impacta (semi-tardia), as quais diferem nos seus ciclos de desenvolvimento, foram cultivadas em Uberaba na safra 2009/2010. A validação para a cultivar UFUS-Impacta foi conduzida comparando os dados observados e simulados de produtividade considerando três diferentes datas de semeadura na safra 2002/2003 em Uberlândia, MG. Foram utilizados dados meteorológicos diários de seis estações meteorológicas do Instituto Nacional de Meteorologia (INMET). Para determinar o desempenho das cultivares de soja e o efeito da ferrugem na produtividade, utilizou-se três diferentes cenários denominados de: não ocorrência de ferrugem (NOR) e ocorrência de ferrugem nas concentrações de inóculo de U5.000 e U10.000 urediniósporos/mL. Para todos os ambientes estudados, a cultivar precoce teve o melhor desempenho em relação a cultivar semi-tardia. A ferrugem da soja teve maior impacto na produção para o cenário U10.000 do que para o cenário U5.000. O melhor desempenho das cultivares de soja foram para as cidades de Araxá e Uberaba. A área Sul-Sudeste do Triângulo Mineiro/Alto Paranaíba foi a mais sensível ao efeito da ferrugem na produtividade em comparação com a região norte.

PALAVRAS-CHAVE; *Glycine max*. Modelagem. *Phakopsora pachyrhizi*.

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