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Influence of the temperature and relative humidity on the incidence of wheat leaf rust (*Puccinia Triticina* Eriks.) in southern Sonora, Mexico, during three crop seasons

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Abstract

The influence of climate upon a plant disease is a consequence of the causal agent and its interaction with the host plant. Plants present distinctive elements by the effect of climate, whether they are adverse or beneficial to their growth and development, as well as for their exposure or protection from those climatic factors. The objective of this work was to analyze the influence of temperature and relative humidity in relation to commercial wheat fields which presented leaf rust in different areas of the southern region of the state of Sonora, Mexico, during the crop seasons 2017-2018, 2018-2019, and 2019-2020. Weather data were recorded from 23 weather stations that belong to the automated weather station network of the state of Sonora which comprise the Yaqui and Mayo Valleys. A Voronoi diagram was constructed to delimit the region which corresponded to each weather station, and so to locate each of the commercial wheat fields with leaf rust incidence, in order to analyze the weeks in which disease incidence was high. A "t student test" of independent samples was performed in order to compare the weather variables (average, maximum and minimum temperature, as well as relative humidity) during the three crop seasons, from the weather stations where commercial wheat fields were detected with the presence of leaf rust, with respect to those where the disease was not present. Relative humidity was the main key factor for the presence of leaf rust, since it is the variable where the mean of groups with and without the presence of leaf rust, showed statistical significant difference in each crop season, unlike the average and the minimum temperature which showed difference only during the 2017-2018 crop season, and the maximum temperature during 2019-2020.

Keywords: Leaf Rust; *Puccinia Triticina*; Wheat; Temperature; Relative Humidity

1. Introduction

Wheat is one of the most important cereals for human consumption and it is the second most important in worldwide production [1]. In Mexico, the wheat-growing areas are widely distributed and can be separated into three distinct zones by the two mountain ranges: The eastern lowlands east of the Sierra Madre Oriental mountain range, the Highland Plateau between the Sierra Madre Oriental and the Sierra Madre Occidental, and the Pacific region [2]. Wheat production takes place in an area of 543,258.64 ha in 22 states, but it is concentrated in the states of Sonora (52.70%), Guanajuato (10.81%), Baja California (9.59%), Sinaloa (7.29%), Michoacán (7.52%), Jalisco (4.38%), and Chihuahua (2.88%) with a total grain production in the country of 3,266,511.53 t in 2021 [3].

Leaf or brown rust of wheat caused by the fungus *Puccinia Triticina* Eriks. Is a major disease of wheat worldwide. The causal agent can survive within the same environmental conditions in which the wheat leaf survives; it can infect leaves when dew periods of three hours or less occur at temperatures of about 20 °C; more infections take place with longer dew periods. Losses to this disease are generally low (< 10%), but under some conditions can be severe reaching more than 30% [4]. Areas predisposed to leaf rust in the eastern low-lands of Mexico include those that cross the Texas border

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from the Mexican states of Coahuila, Tamaulipas, and San Luis Potosí; the Highland Plateau in the states of Chihuahua, Jalisco, Mexico, Tlaxcala, Guanajuato, and Michoacán; and in the Pacific region in Sinaloa and Southern Sonora [2]. In southern Sonora, leaf rust is an endemic and important disease of wheat which has caused serious epiphytotics [5,6], and therefore, proper control relies on the effort on breeding for resistance and fungicide applications [7,8].

The influence of climate upon a plant disease is a consequence of the causal agent and its interaction with the host plant. In the case of plant diseases, the main weather factors are temperature, relative humidity, and rainfall but they act together and may influence great damage to the plant [9]. In the southern part of the state of Sonora, Mexico, the Yaqui and Mayo Valleys are regions where climatic conditions are different, as it was shown in 1991, when the highest levels of infection by Karnal bunt were recorded in the Mayo Valley [10]. The same phenomenon occurs with the appearance and development of stripe rust, leaf rust, and spot blotch of wheat in the two valleys [11,12]. Several studies that have been carried out using the data provided by weather stations [9,13,14], have demonstrated that the fluctuation of the temperature and the humidity between sites of the Yaqui and Mayo Valleys induce differences in yield of crops, and have influence upon the presence and incidence of pests and diseases in the different areas of the valleys. Plants present distinctive elements by the effect of climate, whether they are adverse or beneficial to their growth and development, as well as for their exposure or protection from those climatic factors. Studies carried out in southern Sonora have corroborated that the presence of pests and diseases of wheat have been more severe in different areas of the region, as a consequence of climatic conditions which have favored the causal agents.

The Voronoi diagram also called a Voronoi tessellation, decomposition, partition, or a Dirichlet tessellation, is a partition of a plane into regions close to each of a given set of objects which are finitely many points in the plane (called seeds, sites, or generators). For each seed there is a corresponding region, called a Voronoi cell, consisting of all points of the plane closer to that seed than to any other. Voronoi cells are also known as Thiessen polygons [15,16]; a point in any given Thiessen polygon indicates that it is closer to that generating point than to any other, and for every other pixel on the image, the Thiessen polygon takes the color of the nearest control point. Voronoi diagrams help understand the proximity and distance of features, and have practical and theoretical applications in many fields, mainly in science, technology, and in visual art [17,18]. The objective of this work was to analyze the influence of temperature and relative humidity in relation to commercial wheat fields which presented leaf rust in different areas of the southern region of the state of Sonora, Mexico, during the crop seasons 2017-2018, 2018-2019, and 2019-2020.

2. Materials and methods

Data of air temperature (specific heat grade of the air) and relative humidity (relationship between the amount of water vapor that an air mass has and the maximum that it could have), from twenty three weather stations from the automated weather station network (REMAS) [19] of the state of Sonora, which comprise the Yaqui and Mayo Valleys were used (Figure 1), since they have an important role in relation to the proper development of a crop [20] and upon the development of pests and diseases [9].

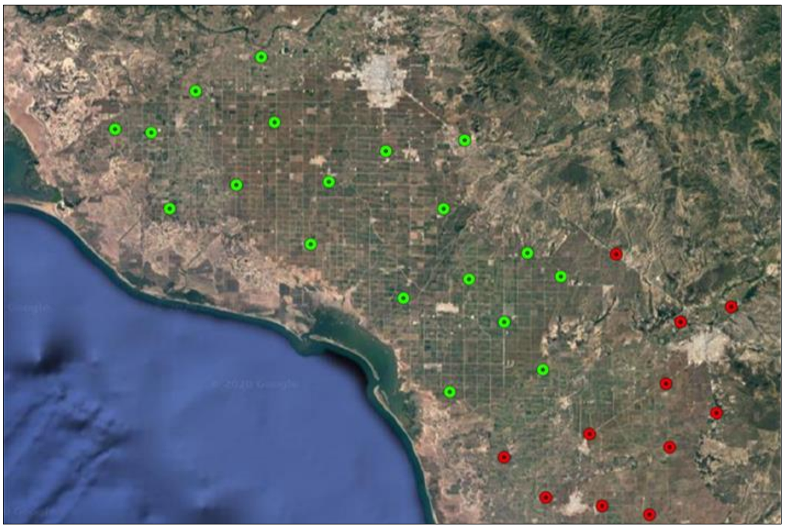

Figure 1 Geographic location of the weather stations in the Yaqui (green circles) and Mayo (red circles) Valleys

A Voronoi diagram was built since it divides a plane into a group of points that define regions, as it is the case of the Yaqui and Mayo Valleys and the location of the weather stations. A delimited region was assigned to each station by borders, which in turn are formed by straight or semi-straight segments; this was done by using the tool QGIS3.

Then, wheat commercial fields with the presence of leaf rust during the crop seasons 2017-2018, 2018-2019, and 2019-2020 were located as well as the closest weather station to those fields. A data base was generated from SIMROYA (Monitoring System for Rusts of Wheat) [21] as well as from the weekly bulletins published by the local plant health councils. The relationship between each field with leaf rust and the closest weather station was established through the Voronoi diagram; then, the analysis of the different weeks with the presence of the disease was performed for each crop season separately.

Once the weeks with the greatest number of affected wheat fields were identified, data from the two previous weeks to the presence of the disease were taken into consideration (incubation period of the fungus), according to each weather station which corresponded to the affected fields. Later on, a comparison of weather variables (average temperature, maximum temperature, minimum temperature and relative humidity) was carried out between stations where wheat fields were affected by rust and those in which there was no rust. An analysis of student "t" test of independent samples was performed in order to determine if there was significant differences between means, and so consider the variable which predominates the most in the development of the disease in relation with the data.

3. Results and discussion

The Voronoi diagram with 23 polygons corresponding to each of the weather stations is shown in Figure 2, covering areas where commercial wheat and other crops are cultivated as well as noncultivated land.

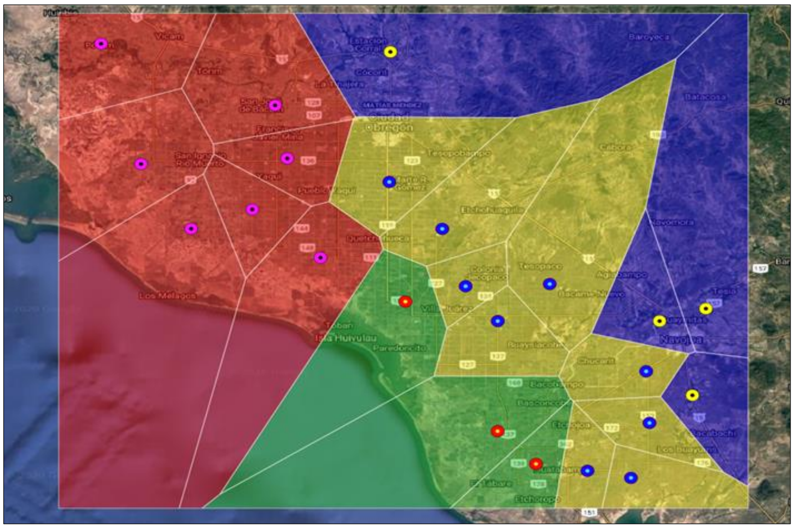

Figure 2 Voronoi diagram showing 23 polygons (regions) corresponding to the weather stations in the Yaqui and Mayo Valleys, Sonora, Mexico

The data base from SIMROYA during the crop seasons 2017-2018, 2018-2019, and 2019-2020 and from the weekly bulletins published by the local plant health councils are depicted in Figure 3.

During the crop season 2017-2018, the range of fields affected with leaf rust was 2 to 76; during the weeks No. 5 of the calendar (from January 29 to February 4) to 8 (from February 19 to 25), the number of fields affected was low (5, 5, 2, and 7, respectively); then, it increased to 15 in week No. 9 (from February 26 to March 4).

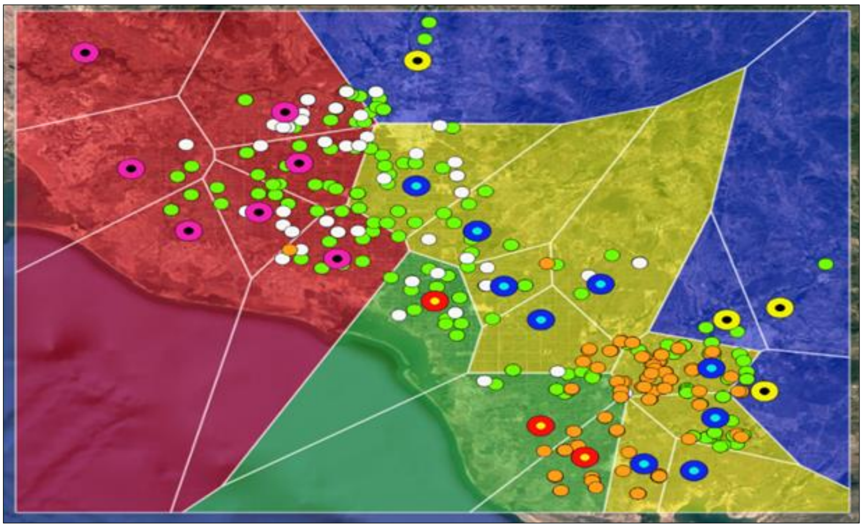

Figure 3 Geographic location of wheat fields affected by leaf rust in each polygon of the Voronoi diagram in the Yaqui and Mayo Valleys, Sonora, Mexico. Small green circles represent fields during the crop season 2017-2018; white circles crop season 2018-2019; and orange circles crop season 2019-2020

Weeks No. 10 to 12 (from March 5 to 25) had the highest number of fields affected with rust (32, 76, and 63, respectively), although weeks No. 13 (from March 26 to April 1) and 14 (from April 2 to 8) had 23 and 21, respectively. There were only 4 fields affected in week No. 15. Weeks No. To 14 accounted for 90.9% of the affected fields (Figure 4). The total number of fields affected by rust were 253.

During the crop season 2018-2019, the range of fields affected with leaf rust was 1 to 27, and there were 5 weeks where there was no detection of wheat fields affected with the disease. Weeks No. 12 to 14 (from March 19 to April 8) had the highest number of fields affected with rust (13, 18, and 27, respectively); weeks No. 8 (from February 19 to 25), 9 (from February 26 to March 4), and 11 (from March 12 to 18) had 2, 1, and 2, respectively. The total number of fields affected by rust were 63.

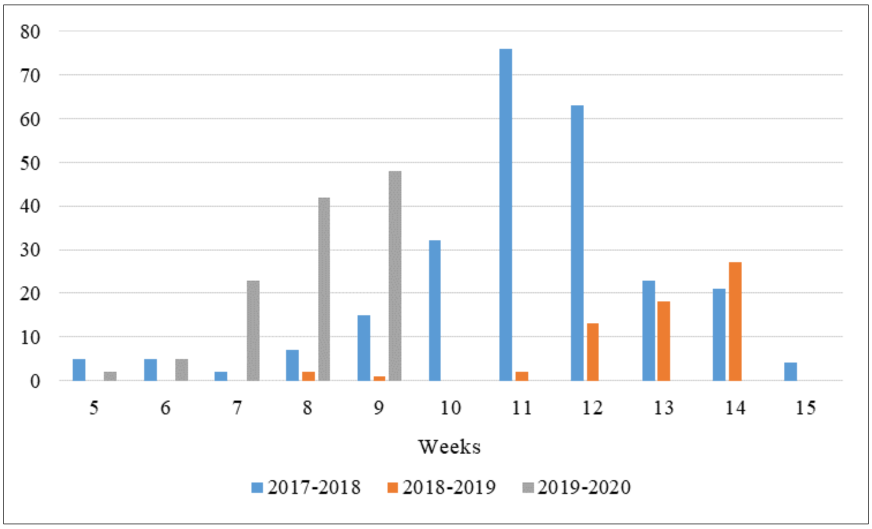

Figure 4 Number of wheat fields recorded with leaf rust from week 5 to 15 in three crop seasons

During the crop season 2019-2020, the range of fields affected with leaf rust was 2 to 48, and there were 6 weeks (from March 4 to April 14) where there was no detection of wheat fields with the disease. Weeks No. 7 (from February 12 to 18), 8 (from February 19 to 25), and 9 (from February 26 to March 3) had the highest number of fields affected with rust (23, 42, and 48, respectively); weeks No. 5 (from January 29 to February 4) and 6 (from February 5 to 11) had 2 and 5, respectively. The total number of fields affected by rust were 120.

During the crop season 2017-2018, the mean temperature of group No. 1 which showed leaf rust, was 16.04°C, while group No. 2 (with no disease) had 16.62°C; the maximum and minimum temperatures were 27.77 and 8.21°C, and 26.15 and 8.86°C, respectively. The mean relative humidity of group No. 1 was 72.72%, being higher than the mean of group No. 2 with 70.022%. There was a difference between means of the two groups in each of the variables (Table 1).

Results of the Levene test of variance similarity, which helps to determine the t value, show that the significance of the four variables was greater than 0.05 during the crop season 2017-2018, which means that variances are not different, since a $p < 0.05$ is needed to assume that there are differences between variances (Table 1).

It also shows bilateral significance, which is the result of the t test, assuming that variances are equal; the *p* value of the variables mean temperature, minimum temperature, and relative humidity are lower than 0.05, which implies that the mean difference between groups is real (they are statistically significant), while the *p* value of maximum temperature is 0.429 which is greater than 0.05, and therefore, there is not a significant difference between the means of both groups.

Table 1 Results of the "student t test" for temperature and relative humidity recorded in wheat fields with rust and without rust during the 2017-2018 crop season in the Yaqui and Mayo Valleys, Sonora, Mexico

	Levene´s test		**Statistical test**		
Variable	**F**	**Value of *p***	**T**	**DF**	**Value of *p* (bilateral)**
Mean temperature	0.435	0.510	-2.157	320	0.032
Maximum temperature	0.252	0.616	-0.791	320	0.429
Minimum temperature	0.190	0.663	-2.326	320	0.021
Relative humidity	1.843	0.176	2.079	320	0.038

Regarding the crop season 2018-2019, the mean temperature of the group No. 1 was 16.95°C, while group No. 2 had 16.79°C; the maximum and minimum temperatures were 26.62 and 8.99°C, and 26.17 and 8.86°C, respectively. The mean relative humidity of group No. 1 was 70.71%, being lower than the mean of group No. 2 with 73.80%. There was a difference between means of the two groups in each of the variables.

Results of the Levene test indicate that the variables mean and minimum temperatures were lower than 0.05, which means that variances are different, while the variables maximum temperature and relative humidity were greater than 0.05, therefore, it is assumed that variances are similar (Table 2).

The *p* value of relative humidity is 0.001 and the only one below 0.05 which indicates that the difference of the mean of the groups are statistically significant, and the *p* value of the rest of the variables is greater than 0.05; and so, it is assumed that there is no significant difference between the mean of the two groups (Table 2).

Table 2 Results of the "student t test" for temperature and relative humidity recorded in wheat fields with rust and without rust during the 2018-2019 crop season in the Yaqui and Mayo Valleys, Sonora, Mexico

	Levene´s test		**Statistical test**		
Variable	**F**	**Value of *p***	**T**	**DF**	**Value of *p* (bilateral)**
Mean temperature	4.657	0.032	0.953	119.211	0.343
Maximum temperature	0.001	0.996	1.245	320	0.214
Minimum temperature	4.357	0.038	0.458	124.998	0.648
Relative humidity	0.007	0.935	-3.521	320	0.001

For the crop season 2019-2020, mean, minimum and maximum temperatures in group No. 1 (16.81, 9.82, and 25.17°C) were lower than those in group No. 2 (17.19, 10.02, 26.12°C), while the relative humidity of group No.2 (71.72%) was lower than the relative humidity of group No. 1 (76.61%).

The significance that the Levene test shows for relative humidity was 0.029, which indicates that the variances are not similar, and the rest of the variables showed a significance value greater than 0.05 which means that the variances are similar (Table 3).

The *p* value of maximum temperature was 0.004 and again the value of the relative humidity was 0.001, so these two variables showed a *p* value below 0.05 which means a statistical significant difference between the mean of the two. On the contrary, the mean and minimum temperature, where it is assumed that there is no significant difference between the mean of the two groups (Table 3).

Table 3 Results of the “student t test” for temperature and relative humidity recorded in wheat fields with rust and without rust during the 2019-2020 crop season in the Yaqui and Mayo Valleys, Sonora, Mexico

	Levene´s test		**Statistical test**		
Variable	**F**	**Value of *p***	**T**	**DF**	**Value of *p* (bilateral)**
Mean temperature	0.044	0.835	-1.238	320	0.217
Maximum temperature	0.403	0.526	-2.89	320	0.004
Minimum temperature	1.134	0.288	-0.487	320	0.627
Relative humidity	4.796	0.029	6.778	178.906	0.001

Based on these results, it would be useful to analyze each wheat season where climatic data are available, in order to make up a chart with analogue seasons, and therefore come up with practical recommendations for farmers regarding crop management. This is specially important when there is an early appearance of leaf rust in the region. Commonly, the disease first shows up in the area regarded as “zone 4” by Torres-Cruz *et al*. [22] characterized by an average temperature of 22.93°C during crop seasons 2014-2015 to 2018-2019 and an average relative humidity of 72.86% during the same period of time. In the southern part of the state of Sonora, the presence of dew (Figure 5) in the wheat crop is a common event during the season because of the fluctuation of temperature during the day-night. The presence of free water on the wheat plant favors greatly the germination of urediospores of the fungus, and consequently the infection of plant tissue.

Figure 5 Dew formation on the wheat crop

4. Conclusion

Relative humidity was the variable where the mean of the group with leaf rust incidence and the group which did not have presence of rust, showed statistical significant difference in each crop season, while the mean and minimum temperature only showed differences in crop season 2017-2018, and the maximum temperature in crop season 2019-

2020. Therefore, relative humidity is the main factor that influences the development of leaf rust on the wheat crop in southern Sonora.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this document.

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