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Application of Calcium and Sulfur in the Severity of *Puccinia coronata* f. sp. *avenae*

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***Keywords*— Avena sativa L., fertilizing, Rust.**

***Abstract*— *Among the diseases that manifest in the cultivation of oats (**Avena sativa**), leaf rust, caused by **Puccinia coronata f. sp. avenae**, has been shown to be the most destructive, being responsible for the decrease in quality and grain yield. Nutritional balance can contribute to plant resistance to disease. In order to evaluate the effect of different doses of calcium and sulfur on leaf rust severity and on the productivity of the IPR Afrodite white oat cultivar, an experiment was installed in the municipality of Ponta Grossa-PR. The experimental design used was randomized blocks, with 5 treatments and 4 repetitions. The treatments consisted of different doses of SE-SUPER fertilizer (CaO 31% + S 13.50%) applied at sowing: T1 (control, 0Kg.há$^{-1}$), T2 (50Kg.há$^{-1}$), T3 (100kg.ha^{-1}), T4 (150kg.ha^{-1}) and T5 (200kg.ha^{-1}). The assessments of leaf rust incidence and severity are carried out weekly from the first symptoms, by quantifying the proportion of the affected host tissue. From the first assessment, weekly assessments were carried out, making it possible to calculate the area under the disease progress curve (AUDPG). For the determination of productivity, the yield in kg of grains / ha was calculated, based on the harvested experimental area. There was a difference between treatments for the severity of rust in the six evaluations performed. All doses were equivalent in reducing the AUDPG of the disease, but the treatments with 150 and 200 kg.ha^{-1} of SE SUPER, presented the highest percentages of reduction, 47.21 and 48.00%, respectively. There was no difference in the productivity obtained. Other management strategies must be associated with fertilization with calcium and sulfur to control rust. Other management strategies should be associated with fertilization with calcium and sulfur, contributing to the rational use of pesticides and reducing pollution.*

I. INTRODUCTION

Among the diseases that manifest in the culture of white oats (*Avena sativa* L.), leaf rust, caused by *Puccinia coronata* f. sp. *avenae* Fraser & Led., has been shown to be the most destructive, being responsible for the decrease in grain quality and yield, having caused severe epidemics in all regions of the world where this cereal is grown [18].

The damage caused to the leaves, especially to the flag leaf, causing the reduction of photosynthesis, interferes in the redistribution of the products resulting from this process from the leaves to the grain in formation. This results in withered grains, with little or no commercial and nutritional value [20].

The characteristics linked to the yield most affected by the occurrence of the disease are the average weight of panicles and the weight of 1,000 seeds [3]. Grain yield and quality can decrease by more than 30%, reaching 50% in susceptible cultivars, depending on the level of disease incidence [20] [14].

Spraying with fungicides is the main rust control measure, however, mineral nutrition can contribute to reducing the intensity of the disease [15]. That is, mineral nutrition favors the increase in the thickness of the wax layer of the middle lamella, and the production of phenolic compounds, among other factors that increase the resistance of plants to diseases [10]. The deficiency of the nutrients needed to synthesize chemical compounds and physical barriers, around the point of infection, can result in host susceptibility [15].

Zambolim, Pereira, Cintra [22], consider that, in cases of fungal diseases, the protection promoted by balanced mineral nutrition results in the formation of an efficient physical barrier, with inhibition of hyphae penetration or better control of the cytoplasmic membrane permeability. This prevents the release of sugars and amino acids into the intercellular spaces and constitutes a chemical barrier, with the production or formation of phenolic compounds.

Among the essential mineral nutrients, calcium (Ca) is of great importance in plant defense responses to phytopathogens [12]. Ca can affect the incidence or severity of plant diseases in two ways. First, because it contributes to the stability of biomembranes; thus, under low Ca contents, there is an increase in the efflux of low molecular weight compounds, such as sugars, from the cell cytoplasm to the apoplast, favoring phytopathogens [15]. In addition to this function, Ca plays a critical role in cell division and development, in the structure of the cell wall and in the formation of the middle lamella [12] [10].

Many phytopathogenic fungi and bacteria invade the tissues, producing extracellular pectinolytic enzymes, such as polygalacturonase [9], which dissolves the middle lamella of host plants. The activity of this enzyme is drastically inhibited by the presence of calcium [12] [15].

Sulfur (S) also plays an important role in the plant's defense mechanism against pests and diseases. S is a lipophilic element, it can act through the cell wall of fungi, destabilizing the redox reaction of the pathogen metabolism [22]. These authors affirm that the product is considered to be in contact, eliminating and / or eradicating the structures of fungi on the surface of plants and also participates in the formation of amino acids and proteins, in the process of photosynthesis and in the defense mechanisms of the plant.

Healthy plants contain a wide variety of secondary metabolites, many of which contain S in their structure. These compounds are present either in their biologically active form or stored as inactive precursors, which are converted by the active form by the action of enzymes in response to the attack of the pathogen or pest. Little is known about how it works [21] [8].

Knowing the effects of these mineral nutrients on the rust intensity of white oats can help to develop management strategies and, consequently, reduce the applications of pesticides, the production cost and the environmental impact. Within this context, the aim of the present work was to evaluate different doses of organic fertilizer (based on calcium and sulfur) in the culture of white oats and their interference in leaf rust severity and productivity, in the region of Campos Gerais, Paraná.

II. MATERIAL AND METHODS

The experiment was carried out in the educational and experimental area of Unicesumar, Campus Ponta Grossa, located at 25 ° 13 'latitude and 50 ° 03' longitude, and 900 m altitude. The climate in this place is humid subtropical, classified as CFb, according to Köppen. The average annual rainfall is approximately 1550 mm. The cultivar used will be IPR Afrodite, the seeds were donated by the Instituto Agronômico do Paraná (IAPAR). Soil analysis was performed before the experiment was implemented, obtaining: pH in water 5.6, P (Mehlich 1): 5.11 $mg.dm^{-3}$, K: 60 $mg.dm^{-3}$, S (phosphate monocalcium in acetic acid): 5.8 $mg.dm^{-3}$, Ca: 2.9 $cmolc.dm^{-3}$, Mg: 1.0 $cmolc.dm^{-3}$, effective CTC (t): 5.5 $cmolc.dm^{-3}$, MO: 1.8 $dag.kg^{-1}$.

The experimental design was a randomized block with 5 treatments and four replications, making a total of 20 plots, each plot having five 3m lines, spaced 0.2 m apart. The treatments consisted of the application of different doses of the SE SUPER fertilizer (CaO 31% + S 13.50%) applied at sowing (together with the basic fertilization), T1 (control, 0 Kg ha^{-1} SE SUPER); T2 (50 kg ha^{-1} SE SUPER), T3 (100 kg ha^{-1} SE SUPER), T4 (150 kg ha^{-1} SE SUPER) and T5 (200 kg ha^{-1} SE SUPER). The SE SUPER fertilizer was supplied (donated) by the company Polli Fertilizantes Especiais, which has the IBD certificate, used in organic agriculture.

The sowing was in the winter of 2020. The planting system with mechanical seeding was adopted. Sowing took place on June 24, 2020, using the density of 100 kg ha^{-1} of seeds, with an average viability of 80%. The basic fertilization was standard, using 30 kg ha^{-1} of N and 60 kg ha^{-1} of P_2O_5. The crop emerged on July 3, and the standard cover fertilization (40 kg of N / ha) was carried out on July 13.

The experiment was under natural inoculation of the disease (leaf rust). The assessments of leaf rust incidence and severity were performed weekly during the culture cycle from the first symptoms, by quantifying the proportion of the affected host's tissue. The leaves of 10 plants chosen at random on the two central lines of each plot were evaluated with the aid of a diagrammatic scale [17]. From the first assessment, weekly assessments were carried out, making it possible to calculate the area under the disease progress curve (AUDPG).

$$AUDPG = \sum_{i=1}^{n} [(Yi+1+Yi)x\ 0{,}5]\ [Ti+1-Ti]$$

Where Yi = percentage of leaf area affected by rust in the i-th observation, Ti = time (in days) at the time of the i-th observation and n = total number of observations [19].

The harvest was done manually on October 24, 2020, by collecting four rows of two meters. For the determination of productivity, the yield in kg of grains / ha was calculated, based on the harvested experimental area. The statistical analysis of the data will be done through the free program Sasmi agri. The data of the area under the disease progress curve (AUDPG), will be subjected to analysis of variance (ANOVA), and the discrimination between treatments will be done by the Tukey test at the 5% probability level.

III. RESULTS AND DISCUSSION

Six evaluations of *P. coronata* f. sp. *avenae*, at 31, 38, 49, 56, 64 and 71 days after the emergency (DAE). The lowest severity (0.32%) of the disease occurred at 31 DAE, and the highest (29.20%) at 71 DAE (Table 1).

There was a difference between treatments in the six evaluations performed. The highest percentages of reduction in disease severity were observed in treatments with 150 and 200 kg. ha^{-1} of SE SUPER (Table 1).

Matzen et al. [13], worked with *Bacillus amyloliquefaciens* (ex-*subtilis*) strain QST 713, to control powdery mildew in oats, and were successful in reducing the severity of the disease only at the beginning of the epidemic. Gabardo et al. [9], worked with alternative products (leaf fertilizers) to control Asian rust (*Phakopsora pachyrhizi* Syd. & P. Syd.), Obtaining a reduction in the severity of the disease only when there was low pressure of the inoculum.

There was a difference for the AUDPG, between treatments (Table 1). AUDPG is a useful quantitative summary of disease intensity over time, for comparison over the years, locations or management tactics [11]. All doses were equivalent in reducing the AUDPG of the disease, but the treatments with 150 and 200 kg. ha^{-1} of SE SUPER, presented the highest percentages of reduction, 47.21 and 48.00%, respectively.

Diseases caused by pathogenic fungi are one of the main factors that reduce the productivity and quality of grains in the production of crops [17]. The damage caused to the leaves by rust, especially the flag leaf, causes the reduction of photosynthesis, interferes in the redistribution of the products resulting from this process from the leaves to the grain in formation. This results in withered grains, with little or no commercial and nutritional value [20].

Table 1- Severity (%) of rust (Puccinia coronata F.sp. avenae, at 31 DAE, 38 DAE, 49 DAE, 56 DAE, 64 DAE and 71 DAE, 85 DAE and Area below the disease progress curve (AUDPG), in the different treatments performed on white oats, cultivate IPR Aphrodite, Ponta Grossa / PR, 2020 harvest.

Treatment	31 DAE	38 DAE	49 DAE	56 DAE	64 DAE	71 DAE	AUDPG
Witness	0,65 a	13,50 a	14,00 a	13,85 a	21, 20 a	29,20 a	670,91 a
50 kg.ha^{-1}	0,40 ab	11,50 b	11,50 ab	6,45 b	14,35 b	22,95 b	453,46 b
100 kg.ha^{-1}	0,40 ab	5,87 c	9,25 ab	7,55 b	13,40 b	20,70 b	367,10 b
150 kg.ha^{-1}	0,35 ab	5,12 c	8,25 ab	7,25 b	14,15 b	20,60 b	354,20 b
200 kg.ha^{-1}	0,32 b	4,37 c	5,50 b	7,00 b	14,35 b	19,95 b	348,83 b
C.V. (%)	32,57	23,11	29,11	29,88	19,83	12,69	12,51

* Averages followed by the same lowercase letter in the column do not differ by Tukey's test at 5% significance; Original data. DAE = days after emergency; C.V. = coefficient of variation.

Although the doses of calcium and sulfur reduced the disease's severity and AUDPG (Table 1), there was no statistical difference between treatments for the obtained productivity. The lowest productivity obtained was in the control (1304.69 Kg.ha^{-1}) and the highest (1546.86 Kg.ha^{-1}) in the treatment with 200Kg.ha^{-1} of SE SUPER (Table 2).

The yields obtained are below the average productivity of Paraná, which reached 1,889 kg.ha^{-1} in the 2020 harvest [6]. The difference between the treatment (200 Kg.ha^{-1} of SE SUPER), which obtained the highest productivity average and the state average was 342.14 Kg.ha^{-1}, we emphasize that in the present experiment there were no other strategies for disease management, in addition to fertilization with calcium and sulfur (Table 2).

The importance of culture has been growing exponentially in Brazil, and the planted area went from 106.1 thousand ha-1 in 2007 to 291.5 thousand ha^{-1} in 2017, an increase of 174% [4]. For 2019, the planted area is approximately 372,500 ha^{-1}, corresponding to an increase of more than 80,000 ha^{-1} compared to 2017, the regions with the largest production of white oats in Brazil are Mato Grosso do Sul, Paraná and Rio Grande do Sul respectively. For 2019 the production was 836.3 thousand tons [5].

The increase in cultivation areas proves that, in fact, culture has its place in the consumer market and importance for producing states. However, there are limiting factors for the expansion of culture in Brazil, such as the occurrence of rust.

Table 2 - Productivity (Kg ha^{-1}) as a function of the treatments carried out on white oats, cultivar IPR Aphrodite. Ponta Grossa / PR, 2020 harvest.

Treatment	Productivity (Kg há)
Witness	1304,69 a*
50 kg.ha^{-1}	1346,36 a
100 kg.ha^{-1}	1424,48 a
150 kg.ha^{-1}	1488,02 a
200 kg.ha^{-1}	1546,86 a
C.V. (%)	20,46

* Averages followed by the same lowercase letter in the column do not differ by Tukey's test at 5% significance; Original data; C.V. = coefficient of variation.

Another important issue for the management of the disease is that the use of resistant cultivars is considered the most effective and economical control method for grain rust [16]. However, resistance is not durable for long periods when used in large areas. This is because the rust, being obligatory parasites, co-evolved with their hosts as components of a system very influenced by ecological conditions, that is, any change in the predominant population of the host, results in subsequent changes in the population of the pathogen, so that the balance is restored [1].

Future experiments are necessary, combining, in addition to fertilization with calcium and sulfur, other forms of disease control. Collaborating for the rational use of inputs by farmers in the region, providing alternatives for disease control in white oat crops.

IV. CONCLUSION

There was a difference between treatments for the severity of rust in the six evaluations performed.

There was a difference for the area under the disease progress curve, all treatments differed from the control.

There was no difference in the productivity obtained. Other management strategies must be associated with fertilization with calcium and sulfur to control rust.

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