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Cultivation strategies in irrigated rice area for red rice control: Case study

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ABSTRACT
Red rice (Oriza sativa L.) It is the most important weed for rice cultivation, and can reduce productivity. With the advent of the Clearfield® system, it became possible to control it using herbicides, belonging to the chemical group of imidazolinones. However, several cases of red rice resistant to these herbicides have already been identified, intensifying the problem especially when rice is sown in dry soil. The objective of this work was to describe the potential of different cropping systems in rice areas to reduce the presence of red rice resistant to these herbicides, through a case study conducted in a field. The work was conducted in the municipality of Manoel Viana, located on the Western Border of Rio Grande do Sul, during the 2021/2022 agricultural year, using 3 treatments: minimum crop (CM) and pre-germinated (PG). This commercial crop had been implanted under the minimum tillage system for several years before the implementation of the treatments. The presence of susceptible and resistant red rice was evaluated in soil samples collected after the 2021/2022 harvest. The samples were then stratified at the following depths: 0.0-0.15m and 0.15-0.30m. At the same soil collection points, in each field, rice was harvested to estimate grain yield (kgha-1), grain mass and whole grain yield. A higher number of red rice seeds was observed in the area cultivated in the pre-germinated system, but only 7.95% of these seeds generated plants in the previous harvest. However, in minimum cultivation, 33.86% of the seeds generated plants. This result, combined with the higher average yield and percentage of whole grains, leads to the conclusion that the use of the pre-germinated system, in addition to reducing problems with red rice, can also improve the economic gain of the products.

Keywords: Pre-germination, Minimum tillage, Production systems.

1 INTRODUCTION

Rice (*Oriza Sativa* L.*)* It is the second most cultivated and consumed cereal in the world, being the staple food for about 3 billion people. Globally, in terms of cultivated area, productivity, and production, Brazil ranks 10th, 17th, and 10th, respectively (FAO, 2020).

According to CONAB (2022), Brazil estimates a rice area of 1.5 million hectares in the 2022/2023 harvest, of which 1.05 million hectares are in Rio Grande do Sul (RS). With 73.4% of the total, RS is the national leader both in cultivated area and in productivity and production, followed by the state of Santa Catarina (SC).

The western frontier is responsible for 29.7% (284,654 thousand hectares) of the irrigated rice area in the state, with an average productivity in the last harvest of 8,315 Kgha-1 (166.3 scha-1) (IRGA, 2022).

One of the main factors that limit this productivity in irrigated rice is the existence of weeds, which, according to FLECK (2004), can cause losses of more than 80% in grain yield.

In the management of rice crops, one of the main problems is related to the control of these weeds, more specifically red rice, which is responsible for reducing the productivity and quality of cultivated rice.

To manage red rice, rice producers need to use specific practices to control this weed, which range from the modification of the cultivation system, choice of cultivar, sowing time, among others (MARCHEZAN, 1994).

The techniques mentioned above are among the recommended and most used practices for the management of this weed. These practices are related to the control of red rice, as well as to the productivity and quality of grains/seeds.

The main characteristics that make red rice so aggressive are due to its ability to compete with cultivated rice, reducing the interception of radiation and nutrient absorption. In addition, the reduction in the quality or commercial value of the harvested product, since, in addition to potentially reducing the yield of whole grains, it increases the costs of processing rice, requiring a specific structure for the separation or even the honing of the grains (GOSS; BROWN, 1939). Natural threshing at the time of harvest is another aspect that makes it difficult to manage red rice, as a considerable part of the grains is separated from the mother plant and deposited in the soil during or even before harvest, forming a seed bank that will be available in the soil for a new emergence in the following harvest.

2 GENERAL CONCEPTS AND LITERATURE REVIEW

2.1 WEEDS IN RICE

Weeds are plant species that compete for the same natural resources, especially in the early stages of development of the cultivated crop, and develop in areas where they are not desired (AGOSTINETTO, 2015).

Weeds are targets for control in irrigated rice areas. This cultivation system, due to its good fertility and moisture in the soil, leads to the emergence of weeds, which cause the grain to lose quality (ERASMO, 2004).

One of the biggest factors that limit the yield and productivity of a crop is weeds, which in addition to competing for the same nutrients and physical, chemical and biological aspects that the crop needs, cause pests and diseases (PITELLI, 2015).

According to Lacerda (2005), the use of the same soil management system for many consecutive years can alter the vegetative flora of the soil surface and modify the size and composition of the seed bank.

Irrigated rice crops in the state of Rio Grande do Sul have a great diversity of weed species with high infestations, especially red rice (*Oriza sativa L.*), barnyardgrass (*Echinochloa spp.*), junquinho (*Cyperus spp.*), cumin [*Fimbristylis miliaceae (L) Vahl.*], papuan (*Urochloa plantaginea*), mihã (*Digitaria spp.*), arrow hyacinth (*Sagittaria motevidensis*) and angiquinho (*Aeschynomene spp.*) (SOSBAI, 2018).

For weed control, there are several preventive methods to be chosen or even the association of several of them together, from the choice of a quality seed, the systematization of the area, the preparation of the soil, the use of herbicides, rotating them and applying them at the right times (MASCARENHAS; COBUCCI, 2008).

2.2 RED RICE

Red rice is a weed that limits the yield and productivity of irrigated rice crops in Rio Grande do Sul, due to its degree of infestation and difficulty in control. In addition, its presence causes a reduction in the commercial value of the final product and also increases the cost of production (SANTOS et al., 2007).

Red rice competes for the same nutrients as commercial rice, having a higher efficiency with the use of Nitrogen, which is why it ends up using around 60% when applied (BURGOS et al., 2006).

The origin of the name red rice comes from the reddish color of its pericarp (Figure 1), due to the accumulation of tannin or anthocyanin (BOÊNO et al., 2009). It is part of the same species as commercial rice, with similar physiological, biochemical and morphological aspects (SCHWANKE et al., 2008).

Figure 1 - Red rice grains without the husk

Source: The authors.

Its coloration can vary from light red to dark red, and its species are divided into three types: wild rice, spontaneous or weedy rice, and cultivated rice (PEREIRA, 2014).

The red rice cultivars exhibit some particularities, such as taller plants (Figure 2), shorter cycle, high tillering capacity, light green leaves and decumbents, presence or absence of arista, early dehiscence of the spikelets, hairiness and adhesion of the palea and lemma in the pericarp, and seed dormancy (AGOSTINETTO et al., 2001).

Figure 2 - Red Rice Plant

Source: The authors.

According to Marchezan (1993), one of the main characteristics that prevents control is the dormancy of the seeds, which remain viable in the soil for approximately 12 years. The plant changes according to climate, sowing density and herbicide resistance.

In seeds there are two types of dormancy: primary and secondary. Primary dormancy is that after harvest, and can be overcome by the storage period or by some physical or chemical method. And secondary dormancy occurs when the seeds are not given favorable conditions for them to germinate (SCHWANKE et al., 2008).

2.2.1 Control Methods for Red Rice

Once installed in the field, red rice grows and coexists with the crop, interfering with plant development. In order to obtain control of this weed, it is necessary to adopt practices that can somehow reduce the infestation before indirectly compromising the crop (LORENZI, 2006).

Irrigated rice is cultivated in different ways and in different regions of the world, and the use of cropping systems is one of the alternatives used by producers to control red rice (AVILA et al., 2000).

Alternating cropping systems is a practice adopted to minimize the damage of this weed. Because they are individuals of the same species, tools such as chemical control have limited efficacy and, when available, end up being perishable, due to the emergence of resistant biotypes (ANDRES et al., 1998).

One of the methods that can be managed red rice is the preparation of the soil in advance with the use of sowing in dry soil, also known as minimum tillage. This system, in addition to participating in rice management, reduces crop costs by having a smaller number of operations for soil preparation (AGOSTINETTO et al., 2001).

Minimum tillage is between conventional tillage and no-tillage, there is less soil tillage than the conventional system during sowing (SOSBAI, 2018).

As red rice has a greater height, compared to cultivated rice, it is possible to make use of another management practice: the use of the chemical bar. This system consists of passing a bar over the rice with a tube with ropes soaked in glyphosate (SOUZA, 1985), which can be done manually or with the help of a tractor.

According to SOSBAI (2018), the use of pre-germinated seeds is summarized in the immersion of seeds in water, remaining for 24 to 36 hours in porous bags or tanks, which then go through the incubation process, with the emission of the coleoptile and radicle, identifying the pre-germination process. From there, sowing is done in a row, in systematized frames already flooded with a 5cm water depth.

The use of the Clearfild® system can reduce the seed bank of red rice, this system consists of the use of herbicide-resistant genotypes of the chemical group of imidazolinones (MARCHEZAN, 2011a).

2.3 CULTIVATION SYSTEMS

Irrigated rice is sown in different cropping systems, which differ in terms of tillage time, types of sowing systems, and initial water management. The systems are divided into conventional cultivation, minimum tillage, no-tillage, pre-germinated and transplantation of seedlings (SOSBAI, 2018).

In the conventional cultivation system, the area is prepared using equipment according to the soil of the area, the depth of preparation and the condition of coverage, and initial preparation of the soil and then secondary preparation can be carried out (SOSBAI, 2018).

Minimum tillage has its soil preparation anticipated, being in autumn or spring, facilitating the decomposition of the straw and the use of implements to readjust the area (SANTOS et al., 2006).

The no-tillage system is appropriate for regions with subtropical and tropical climates, based on technologies for the feasibility of agriculture, with minimal soil movement, no degradation, and can minimize losses of correctives, fertilizers, and soil cover (ANDRADE et al., 2018).

The pre-germinated planting system is defined as a set of techniques for cultivating irrigated rice, in fully systematized areas, and the previously germinated seeds are released in leveled and flooded frames (EMBRAPA, 2005).

Even though it can be grown in several systems, if the same system is repeated over the years, there may be an increase in the emergence of weeds, especially red rice. Thus, rotation of cropping systems can also be considered a practice of integrated weed management.

In Rio Grande do Sul, 2021/2022 harvest, 57.9% of the rice area was under minimum cultivation, while 13.3% was under pre-germinated cultivation. The pre-germinated system, predominantly in the Coastal Plain (internal and external) and Central (IRGA, 2021) regions.

2.4 CHEMICAL CONTROL

The use of herbicides for weed control has been one of the most widely used methods in irrigated rice crops. The use of chemical control combined with other control systems helps to reduce weed competition early in the crop cycle (Rubin et al., 2014).

Physicochemical characteristics of the soil, soil management, cost, weed species, whether there are resistant plants, and the efficiency on the weed in which it will be used, are points that must be considered when choosing the correct herbicide (SCHREIBER et al., 2018).

The use, mode of action, mechanism of action, chemical group or type of vegetation to be controlled determine how herbicides should be used and as a result of their application, symptoms appear, from when it is applied to the plant until its death (MENDES, 2011).

The timing of herbicide application should be taken into account for application. They can be used in pre-sowing: this application takes place before sowing and on top of the vegetation cover; Pre-emergence: the application is made right after the rice is sown, before the seedling emergence; pre-emergence at needle point: the application is made before the appearance of the coleoptile of the rice plants on the soil surface; post-emergence: application takes place after rice emergence and in the initial weed development phase (SOSBAI, 2018).

Herbicides with the same active ingredient or those that exert high selective pressure, when used constantly, end up causing an increase in the number of tolerant plants due to the manifestation of resistant biotypes, making their control even more difficult (INOUE; OLIVEIRA JR, 2011).

3 METHODOLOGY

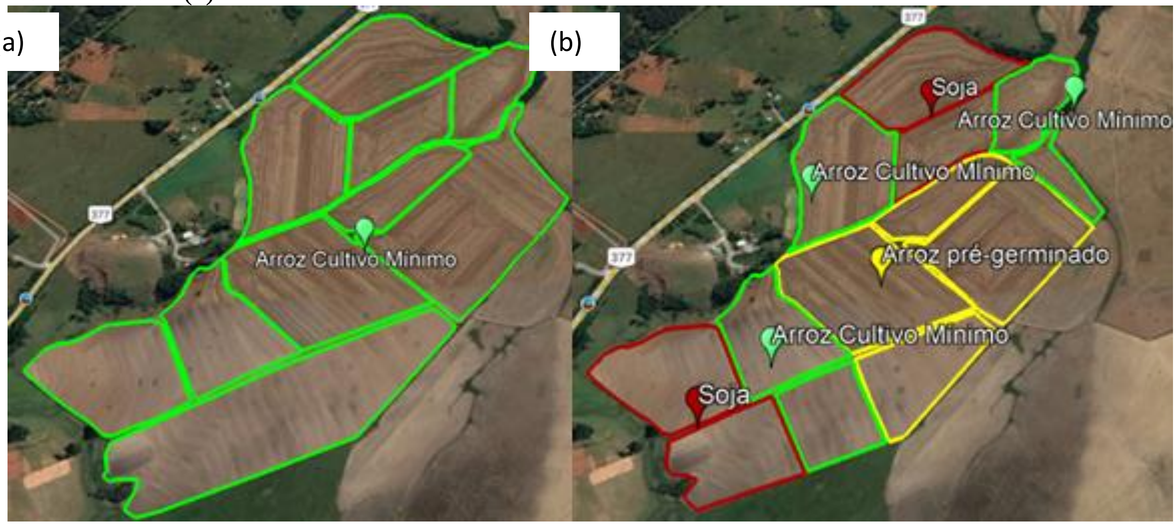
3.1 LOCATION, DESCRIPTION, AND HISTORY OF THE AREA

The work was carried out in a plantation, located in the municipality of Manoel Viana, state of Rio Grande do Sul. The property is located at the geographical coordinates 29º36' 47.22" South and 55º29' 20.72" West, and has an area of approximately 90ha.

The property was acquired in the year 1999. At the time, the areas had a slightly undulating topography, with a natural slope suitable for the cultivation of rice in a rammed earth system. It was an unsystematized area and went through the fallow system for a period of two harvests. In 2002, the project for the creation of frames with leveling at "zero level" was started, and this project was completed in the entire area of the property in 2008. Between the beginning of the 2000s and the 2012/2013 harvest, there was an alternation in the use of pre-germinated cropping systems and minimum cropping with sowing in dry soil. From the 2012/2013 harvest, rice cultivation predominated with the use of minimum tillage throughout the property, since the control of red rice remained at satisfactory levels.

Due to the difficulty of controlling the weed, with the application of herbicides from the chemical group of imidazolinones, in the 2021/2022 harvest there was the beginning of the implementation of the following systems on the property: rice cultivation in the pre-germinated system and soybean cultivation. Figure 3 illustrates the total area of the crop, identifying the cropping system used until the 2020/2021 harvest (Figure 3a) and the distribution of the other systems in the 2021/2022 harvest (Figure 3b).

Figure 3 - Irrigated rice cultivation strategies used between the 2012/2013-2020/2021 harvests (a) and strategies used in the 2021/2022 harvest (b)



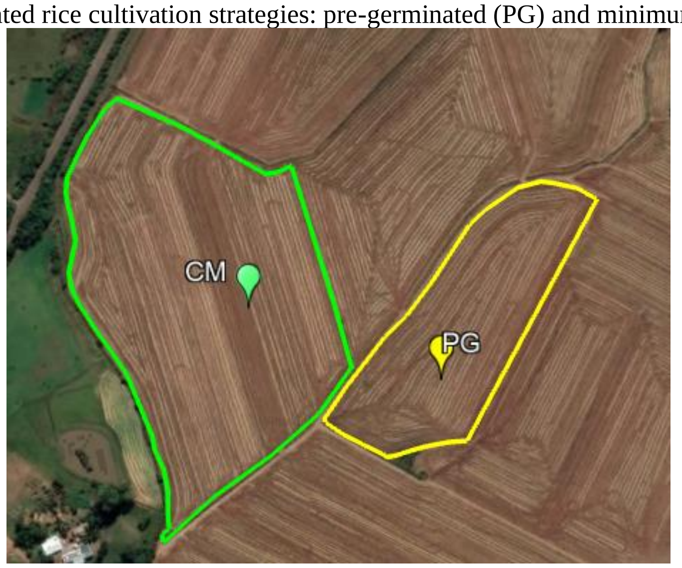
Fonte: Google Earth, 2023.

The soil analysis report of the property presents the following characteristics at a depth of 0.0-0.2m: pH in water of 3.99; base saturation 35.9%; P-Melich (mgdm-3) of 10.4; Organic matter of 2.06%; CTC at pH 7 (cmolcdm-3) of 22.2; K (mgdm-3) of 144.4; Ca(mgdm-3) of 5.2; Mg (mgdm-3) of 2.4; S (mgdm-3) of 14.9; Fe (mgdm-3) of 1.996; Cu (mgdm-3) of 7.4; Zn (mgdm-3) of 3.2; Mn (mgdm-3) of 70.5.

3.2 DESIGN AND DISTRIBUTION OF TREATMENTS IN THE FIELD

To carry out the study, two nearby frames were selected and conducted in two different systems: minimum tillage, with sowing in dry soil (MC); pre-germinated (PG). Figure 4 illustrates the distribution of the frames in the area. The cultivar IRGA 431 CL was used for rice.

Figure 4- Irrigated rice cultivation strategies: pre-germinated (PG) and minimum tillage (CM)



Fonte: Google Earth, 2023.

The pre-germinated rice crop was sown on October 28, 2021, while the minimum crop crop was sown on November 1, 2021.

The fertilization used in this harvest was: 184 Kg of N/hectare, 110 Kg of P_2O_5/hectare and 150 Kg of K_2O/hectare, and for the preparation of the area after the 2020/2021 harvest, a rotary hoe was used and harrowing and leveling operations were carried out.

3.3 EVALUATIONS

Next, the analyses in the units (charts) under study will be described, as well as the form and period in which they were performed.

3.4 GEOREFERENCING OF COLLECTION POINTS

The georeferencing of the collection points in the two frames under study was carried out with the use of a cell phone application, which uses GNSS information from a smartphone, without differential correction (accuracy of 5 meters), called C7 GPS Dados (CR Campeiro 7).

3.5 NUMBER OF RED RICE PLANTS PER UNIT AREA

The number of red rice plants per unit area in the 2021/2022 harvest in the different cropping systems was obtained by directly counting (Figure 5) the number of red rice plants born, at the same points that were georeferenced, with each sample being made in an area of 1m2.

Figure 5 - Counting the number of red rice plants

Source: The authors.

3.6 YIELD AND QUALITY OF RICE GRAINS

The estimation of grain yield, gross income and net income in the 2021/2022 harvest in the different cropping systems was carried out by harvesting rice samples in an area of 1m2 at the same georeferenced points. These were harvested and threshed by hand. The threshed grains were taken to the post-harvest laboratory (LAPÓS) of Unipampa, for the weighing of the entire sample (Figure 6) and for the counting and weighing of 1000 grains (Figure 7). Afterwards, 200g were separated and taken to the Caal Cooperative so that the percentage of whole and broken grain (Figure 8) could be made by means of the rice tasting equipment.

Figure 6 - Weighing of the entire manually threshed sample

Source: own authorship.

Figure 7 - Counting the number of rice seeds for yield estimation

Source: The authors.

Figure 8 - Whole grains after the percentage of whole and broken grains

Source: The authors..

3.7 NUMBER OF SEEDS IN THE SOIL

For the verification and characterization of the viability of the number of susceptible and resistant red rice seeds, 24 soil samples were collected, with the aid of a cutting shovel, in an area of 400cm2 (20cmx20cm), 12 in the frame of rice in minimum cultivation and 12 in the frame of pre-germinated rice, six of these collections were made with a depth of 0-15cm and the other six at a depth of 15-30cm.

In the minimum tillage rice framework, three collections were close to areas with red rice plants (CMPV) and three samples were distant from red rice plants (CMLV). In the pre-germinated rice framework, three samples were close to areas with red rice (PPV) and three were collected far from areas with red rice (PLV). Figure 9 shows the georeferencing of the points.

Figure 9 - Georeferencing of the collection points in the two study frameworks: minimum cultivation near red (CMPV); minimum cultivation away from red (CMLV); pre-germinated near red (PPV); pre-germinated far from red (PLV)

Fonte: Google Earth, 2023.

After collection, the soil of the samples was washed with water (Figure 10) on a sieve with a diameter of 2 mm and mesh number 10, in which the mesh did not allow the rice seeds to pass, and then these seeds were manually separated (Figure 11) from the collected sample. The seeds were then submitted to the germination test (Figure 12) in order to evaluate their ability to germinate if they are in adequate conditions in the field.

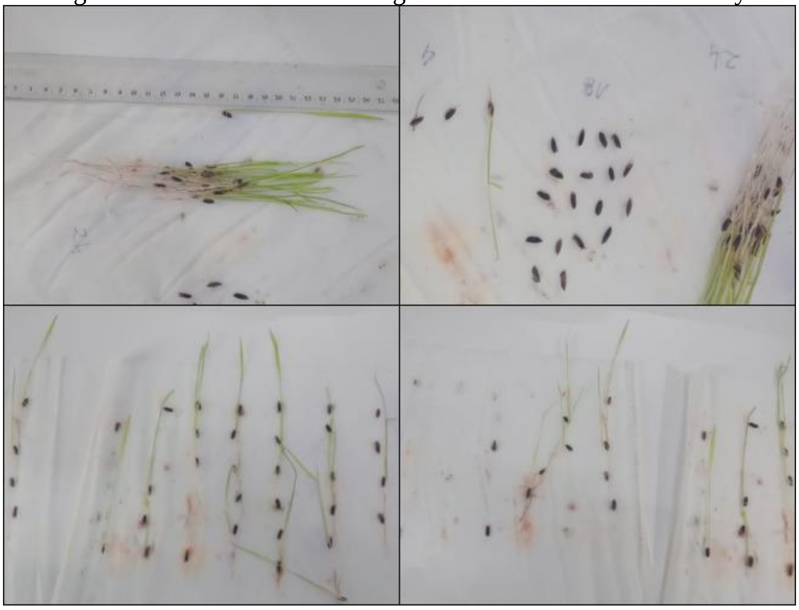
Figure 10 - Soil being washed with water to separate rice grains

Source The authors.

Figure 11 - Red rice seeds manually separated from the collected soil

Source: The authors.

Figure 12 - Red rice seeds after germination test in the laboratory



Source: The authors.

3.8 HERBICIDE RESISTANCE TEST OF IMIDAZOLINONE CHEMICAL GROUP

The evaluation of the herbicide resistance of the chemical group of imidazolinones was carried out following the germination test. The seeds, which gave rise to a vigorous seedling, were then transplanted. When they were transplanted to three common pots and irrigated to the v3 stage, to then receive the application of the herbicide. For the test, a dose of 140g of the herbicide Imazapyr (Kifix®), belonging to the chemical group of imidazolinones, was applied with a manual sprayer.

3.9 DATA ANALYSIS

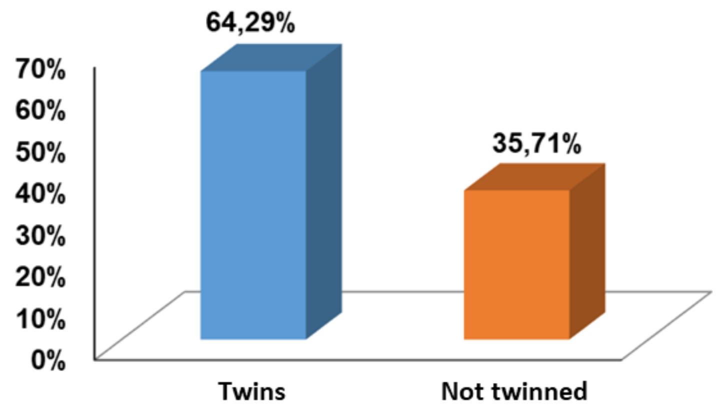
The data from the evaluations were analyzed and compared by means of simple averages, without the use of any means comparison test, given the nature of data collection.

4 RESULTS AND DISCUSSIONS

According to figure 13, the percentage of germination of the seeds collected in the study area was 64.29%. It is not possible to comment on the period in which these seeds remained in the soil. However, it has been reported that the time that red rice seeds remain viable in the soil, able to generate a new plant, can exceed 10 years (REDIN et al., 2020; MARCHEZAN et al., 2003). Another important point is that dormancy is a characteristic present in red rice, which can both delay its emergence, and also mean that a good part of the non-germinated seeds, in the future, can generate new individuals.

According to Pires and Lima (2018), emergence is linked to factors such as humidity, light, temperature, and the dormancy period of the seeds. When seeds receive the appropriate level of these factors, they begin the germination process.

Figure 13 – Percentage of germinated and non-germinated red rice seeds



Source: The authors.

Table 1 shows that the mean number of seeds in the soil is lower in the minimum tillage system. This dynamic is explained, fundamentally, by the repeated use of minimum tillage in previous years, with increased resistance of red rice to acetolactate synthase (ALS) inhibitor herbicides, (WILSON, 1988; AVILA et al., 2000). The pre-germinated system has been used again in this field in recent years, and may have contributed to reducing the seed bank, as concluded by other authors (PETRINI et al., 1996; BIZZI, 1994; ANDRES et al., 1997; SILVA et al., 1998).

Table 1 – Evaluation of the number of plants, number of seeds in the soil and percentage of plants emerged from red rice

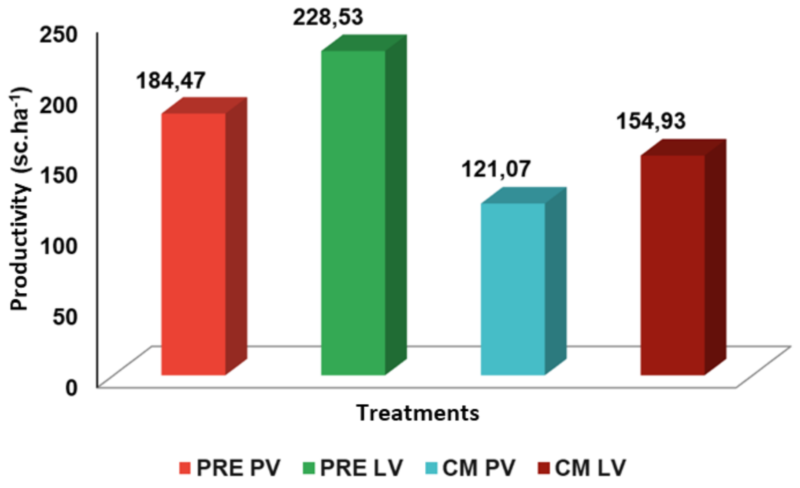
	No. of plants/m² in pre-harvest	**No. of seeds/m² in soil**	**Percentage of plants emerged**
PPV	54,00	625,00	7,95%
PLV	0,00	0,00	0,00%
CM PV	21,33	41,67	33,86%
CM LV	0,00	41,67	0,00%

Source: The authors.

Of the total seeds present in the soil in the area under pre-germinated cultivation, 7.95% of them generated plants (Table 1), even though the germination percentage was greater than 60% (Figure 1). In the case of minimum cultivation, the percentage of seeds that generated plants was 33.86%. This can be attributed to the fact that the minimum tillage system provides better conditions for germination, resulting in a smaller number of seeds in the soil. The emergence of new seedlings was also found by (PIRES; LIMA, 2018), which are directly linked to humidity, temperature, light, and the dormancy period of these seeds, which even after being stimulated by external factors, are linked to the duration of the weed cycle.

Figure 14 shows the yield of rice grains in the different cropping systems, separated according to the proximity or distance of red rice plants. It was observed that the proximity influenced the grain yield. The average yield away from red rice plants was higher yield, both in pre-germinated and minimum crops. These results corroborate (FLECK, 2004; PITELLI, 2015), who mention that the existence of weeds, in this case, red rice, decreases grain productivity. In addition, the average yield in the pre-germinated cropping system was higher than in the minimum cropping.

Figure 14 – Yield in the different treatments, near and far of red rice grains



Source: The authors.

Table 2 shows that, for both cropping systems, there was a tendency to increase the percentage of whole grains in plants that grew without competition with red rice. One of the factors for this to happen is the fact that red rice competes for the same nutrients as the cultivated crop, as mentioned (BURGOS et al.; 2006) and (NOLDIN et al.; 2004), so the presence of red rice can decrease the yield of whole grains.

Table 2 – Percentage of whole and broken grain and weight of 1000 grains

Treatments	Integer (%)	Broken (%)	Weight of 1000 grain(g)
FOR PV	62,84	6,12	27,50
FOR LV	65,11	4,78	27,83
CM PV	59,07	9,18	22,33
CM LV	60,20	8,54	22,33

Source: The authors.

Regarding the resistance of red rice seedlings, after receiving the application of the dose of 140g of the herbicide Imazapyr (Kifix®), when they were at the v3 stage, it was observed that all plants were resistant to application, regardless of the cultivation system used. This reflects the continued use of the same chemical control technology, without rotation of mechanisms of action, which causes them to be lost and the return to pre-germinated cultivation is the only viable way out (RUBIN et al., 2014).

The results of the counting of red rice seeds that were present in the soil at two depths are presented in table 3.It is observed that, at the depth of 0-15cm, the largest number of seeds was found in the pre-germinated system. This demonstrates that this weed is more concentrated in the surface depth of the soil, similar to the results obtained by (REDIN et al., 2020), due to the management with soil turning over a long period of time. When the depth of 15-30cm was evaluated, it was observed that no red rice seeds were found in the soil, regardless of the management system used. This is due to the fact that there is no mobilization of the area at the depth of 15-30cm, not providing conditions for seed germination, which end up suffering complete deterioration. This result corroborates those of (MARCHEZAN, 2011b), who evaluated the emergence of red rice plants resistant to the chemical group of imidazolinones.

Table 3 - Red seeds in soil sampling at two depths

Treatments	Repetition	100 m2	400 m2
0-15cm			
PPV	R1	16	400
PPV	R2	40	1000
PPV	R3	19	475
POS	R1	0	0
POS	R2	0	0
POS	R3	0	0
CM PV	R1	2	50
CM PV	R2	0	0
CM PV	R3	3	75
CM LV	R1	0	0
CM LV	R2	4	100
CM LV	R3	1	25
15-30cm			
PPV	R1	0	0
PPV	R2	0	0
PPV	R3	0	0
POS	R1	0	0
POS	R2	0	0
POS	R3	0	0
CM PV	R1	0	0
CM PV	R2	0	0
CM PV	R3	0	0
CM LV	R1	0	0
CM LV	R2	0	0
CM LV	R3	0	0

The authors.

5 FINAL THOUGHTS

With the results obtained in this case study, it can be seen that the pre-germinated cropping system is more effective in reducing red rice seeds in the soil than the minimum tillage system.

The seeds, when analyzed at the depth of 0-15cm, showed a germination percentage of 64.29%, while at the depth of 15-30cm seeds were found.

Regarding the yield of rice grains, there was an increase in the area managed in a pre-germinated cropping system.

The presence of red rice plants in both cropping systems reduces the yield and quality of rice grains.

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