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# Carryover of [imazapic + imazapyr] on differents crops systems in lowland areas with Clearfield® rice

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**ABSTRACT:** Clearfield® technology is an important tool for chemical weed management in rice fields, however, carryover of these herbicides is still a concern for crops in succession. In this study, we aimed to evaluate the impact of the herbicide Kifix® (imazapic + imazapyr) associated with Clearfield® technology of rice crops on ryegrass in succession, as well as on non-Clearfield® rice and soybean grown in rotation, in addition to the control potential of jointvetch (*Aeschynomene rudis* and *A. denticulata*) from 2016 to 2018. The experiments comprised the application of Kifix® to Clearfield® rice grown in the first experimental year, evaluating its impact (1st summer) on ryegrass grown the following winter, as well as on soybean, rice and non-Clearfield® rice grown the following summer (2nd summer). The results reported reductions in jointvetch density and infestation as Kifix® doses increased; as well as mild damage from Kifix® residues on ryegrass sown in succession to Clearfield® rice, as well as on non-Clearfield® rice and soybean in rotation to Clearfield® rice. In addition, the possibility of residue accumulation of Kifix® in the soil after repeated applications should be verified in further studies.

**Key words:** crop management; herbicide carryover; imidazolinones; *Oryza sativa*

# Carryover de [imazapic+imazapyr] em sistemas de produção em terras baixas com arroz Clearfield®

**RESUMO:** A tecnologia Clearfield® é uma ferramenta importante para o manejo químico de plantas daninhas em arrozais, entretanto, o carryover destes herbicidas ainda é uma preocupação para culturas em sucessão. Neste estudo, objetivamos avaliar o impacto do herbicida Kifix® (imazapic + imazapyr) associado à tecnologia Clearfield® do cultivo de arroz sobre o azevém em sucessão, assim como sobre o arroz e a soja não Clearfield® cultivados em rotação, além do potencial de controle de anguiquinho (*Aeschynomene rudis* e *A. denticulata*) entre 2016 a 2018. Os experimentos compreenderam a aplicação do Kifix® ao arroz Clearfield® cultivado no primeiro ano experimental, avaliando seu impacto (1º verão) sobre o azevém cultivado no inverno seguinte, assim como sobre o arroz, soja e o arroz não Clearfield® cultivado no verão seguinte (2º verão). Os resultados relataram reduções na densidade e infestação de angiquinho conforme o aumento das doses de Kifix®; além de danos leves de resíduos de Kifix® no azevém semeado em sucessão ao arroz Clearfield®, bem como no arroz não Clearfield® e na soja em rotação ao arroz Clearfield®. Além disso, a possibilidade de acúmulo de resíduos de Kifix® no solo, após repetidas aplicações, deve ser verificada em outros estudos.

**Palavras-chave:** manejo de culturas; carryover de herbicidas; imidazolinonas; *Oryza sativa*

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## Introduction

In lowland areas of Southern Brazil, the predominant cultivation is monocrop of paddy rice. In the period between fall and spring, the area may be kept under fallow, or forage species as ryegrass (*Lolium multiflorum*) and clover (*Trifolium* spp.) may be seeded for mulching or cattle feeding (Goulart et al., 2020). Several estival species are tested as options to be rotated with rice, as maize, sorghum and soybean (Emygdio et al., 2017). Among these options, soybean is the most promising one due to its high market value (Goulart et al., 2020).

At the state of Rio Grande do Sul, approximately 3 million hectares of lowland areas are structured with irrigation a drainage canals for rice cropping; from this area, about 2 million hectares have potential to be cropped with soybean (Sosbai, 2018). Most recently, rice farmers from Southern Brazil crop soybeans in rice areas not only for profit, but also to allow controlling rice weed species which are resistant to several herbicides (Andres et al., 2017).

Weed occurrence in rice affects grain yield potential and quality. Among the main weed species infesting rice fields, weedy rice (*Oryza sativa* L.) is the most impacting one, with losses estimated in approximately US$ 300 ha$^{-1}$ (Burgos et al., 2008). As both commercial and weedy rice are the same botanical species, selective chemical control is not easily achieved (Santos et al., 2014).

The jointvetch (*Aeschynomene rudis* and *A. denticulata*) is the main broadleaf weed in paddy rice (Martins et al., 2021). Jointvetch, it is present in approximately 30% of the area cultivated with rice in Rio Grande do Sul State (Galon et al., 2015). In addition to competition for water, light, and nutrients, these weeds have high potential for seed production, which contributes to the seed bank in the soil, damaging successor crops (Concenço et al., 2018).

Clearfield® technology allows selective control of weedy rice, grasses (a. e. *Echinochloa crusgalli*) and broadleaf weeds (a. e. *Aeschynomene* spp.), in commercial rice fields with imidazolinone herbicides applied to resistant cultivars. In Brazil, two herbicides are recommended for this technology: Only® (imazapic + imazethapyr) and Kifix® (imazapic + imazapyr). This group of herbicides usually present moderate to long residual activity in soil, and its persistence in soil depends on several environmental and edaphic properties (Schreiber et al., 2017). Persistence is positive as it contributes for longer weed suppression; on the other side, it is undesirable when it causes injury to crops in succession or rotation (Santos et al., 2014), or when there is risk for environmental contamination or weed resistance evolution (Andres et al., 2017).

Some studies carried out in Brazil report that Clearfield® rice is used for more than two consecutive years in the same fields (Avila et al., 2021), which goes against the recommended by both the Brazilian Irrigated Rice Society (Sosbai, 2018) and the owner of the Clearfield® technology.

In the temperate regions of Southern Brazil, there are complaints about carryover effects of the herbicides associated to the Clearfield® technology on ryegrass (Santos et al., 2014). Complaints also report possible carryover effects on non-Clearfield® rice (Helgueira et al., 2019) and soybean (Fraga et al., 2019), planted in the same area, in rotation to Clearfield® rice.

Thus, we aimed with the present study to assess the carryover effect and control efficiency of *A. rudis* and *A. denticulata* with Kifix® [imazapic + imazapyr] application associated to the Clearfield® technology on ryegrass sowing in succession to Clearfield® rice, as well as on non-Clearfield® rice and soybean sowing in rotation.

## Materials and Methods

The study was installed in the experimental field owned by Embrapa Clima Temperado, Terras Baixas Experimental Station, Capão do Leão (RS), Brazil (geographic coordinates -31.8153; -52.4698). The experiment comprised the application of Kifix® (imazapic 175 g kg$^{-1}$ + imazapyr 525 g kg$^{-1}$) (BASF, Brazil) at doses ranging between 0 and 280 g ha$^{-1}$ to Clearfield® rice grown in all the area at the first experimental year, evaluating its impact on the Clearfield® rice (1$^{st}$ summer), on ryegrass (*L. multiflorum*) grown on the succeeding winter, as well as on soybean and non-Clearfield® rice grown on the following summer cropping season (2$^{nd}$ summer).

For this, the randomized blocks design was used with four replications, with plots measuring 4 × 18 m (72 m$^2$) at the first cropping season (Clearfield® rice in summer and ryegrass in winter), being later split (4 × 8 m - 32 m$^2$) for the second summer cropping season, to allow sowing both non-Clearfield® rice and soybean on the areas where the distinct doses of [imazapic + imazapyr] were applied in the preceding summer.

### First summer crop

The vegetation burndown for the 1$^{st}$ cropping season, prior to sowing, was done with 1440 $g_{a.e.}$ ha$^{-1}$ of glyphosate, seven days before sowing the cultivar Guri INTA CL, on November 9, 2016, in rows spaced in 0.17 m. The base fertilization consisted of 300 kg ha$^{-1}$ of the formula N-P-K 5-25-25 applied to the sowing row. Rice was sowing on November 16, 2016.

Treatments were: (T1) control without herbicide application; (T2) Kifix® 140 g ha$^{-1}$ (24.5 g ha$^{-1}$ imazapic + 73.5 g ha$^{-1}$ imazapyr) and (T3) Kifix® 280 g ha$^{-1}$ (49 g ha$^{-1}$ imazapic + 147 g ha$^{-1}$ imazapyr). The application was carried out one day after sowing (DAS), via precision equipment propelled by $CO_2$, connected to a bar with six 110.02 nozzles spaced in 0.5 m, subjected to the necessary pressure to apply the equivalent to 150 L ha$^{-1}$ of herbicide solution.

Topdressing fertilization was done on two moments: beginning of tillering (December 9, 2016) and before panicle initiation (January 13, 2017), each with 100 kg ha$^{-1}$ of urea (45% N). Irrigation was established on December 9, 2016, 21 days after rice emergence. On December 15, 2016 (36 DAS), 375 g ha$^{-1}$ of quinclorac were applied in all the area, including the control plots without Kifix®, to assist in the control of jointvetch (*A. denticulata* and *A. rudis*).

Throughout the cropping cycle, we evaluated rice emergence curve (0-20 days after sowing - DAS), plant height and dry mass (25 and 60 DAS) as function of the herbicide doses; but as the rice variety Guri INTA CL is tolerant to Kifix®, no effect was reported on the Clearfield® rice (data not shown).

The density and aerial dry mass of jointvetch (*A. denticulata* and *A. rudis*) plants were assessed on December 22, 2016, seven days after the application of quinclorac (but with all plants still alive), and again 35 days after quinclorac application, on January 19, 2017. Jointvetch plants present in 4 $m^2$ samples per plot, were cut to soil level and dried into oven with forced air circulation 65 ± 5 ºC, until constant weight. Also, during this period, the general infestation of the area by weeds was assessed. Weed occurrence was composed mostly by jointvetch, with a few individuals of barnyardgrass and other aquatic macrophytes.

Rice grain yield was assessed at the end of the cycle (March 2017), when two samples of 4 $m^2$ per plot were harvested by hand and threshed, subjected to oven drying with forced air circulation at 65 ± 5 °C, after which the grains were weighed, and their mass corrected to 13% humidity.

### Winter mulching crop

On April 2017, ryegrass (*L. multiflorum*) cv. BRS Ponteio was sown on all the area on early April at seeding rate of 25 kg $ha^{-1}$. No fertilizer was applied to the winter mulching crop, and no mowing was applied to the field at any time; ryegrass was allowed to grow freely.

On October 10, 2017, about 180 days after ryegrass sowing and 328 days after the application of Kifix®, the percentage of the area covered by ryegrass was evaluated by the Point method, by using a point frame for 10 pins, as reported by Barbour et al. (1998). Five sub-samples were taken per plot. The level of occurrence of the main weed species present in the experimental area (*Lolium* and *Panicum*), were evaluated, being the remaining weed species reported into "others". The dry mass of the winter mulching (excluding any weed from the sample), was also evaluated at the same date, as well as the plant height.

### Second summer crop

Non-Clearfield rice and soybean were planted over the ryegrass mulching on November 13 and 14, 2017, respectively. The vegetation burndown was done with 1440 $g_{a.e.}$ $ha^{-1}$ of glyphosate, one day after sowing. Rice cv. BRS Pampa was planted at density of 100 kg $ha^{-1}$ of seeds in rows spaced in 17.5 cm, with base fertilization consisting of 280 kg $ha^{-1}$ of the formula N-P-K 5-25-25 applied to the sowing row. Soybean cv. BMX Ponta iPro was planted at density of 50 kg $ha^{-1}$ of seeds in rows spaced in 45 cm, with base fertilization consisting of 300 kg $ha^{-1}$ of the formula N-P-K 0-25-25 applied to the sowing row, being planted 18 seeds $m^{-1}$ (expecting to establish ~350,000 plants $ha^{-1}$).

No topdressing fertilization was applied to soybean. For rice, topdressing fertilization was done in two moments: beginning of tillering (December 7, 2017) and a few days before panicle initiation (January 17, 2018), each with 100 kg $ha^{-1}$ of urea (45% N). Irrigation was established on December 7, 2017, 21 days after rice emergence.

No other ALS herbicide was used all throughout the duration of the experiment besides the Kifix® doses that constituted the treatments applied in the first summer cropping season. Weeds into soybean plots were controlled by two applications of 900 $g_{a.e.}$ $ha^{-1}$ glyphosate 25 and 45 days after emergence (DAE); rice weeds were controlled with application of 228 $g_{a.e.}$ $ha^{-1}$ of cyhalofop-n-butyl + 300 g $ha^{-1}$ of clomazone on December 6, 2017, followed by flooding one day later.

Rice emergence was evaluated for 25 days from sowing, by counting two static sub-samples with 1 m of row each per plot (7 counts in 25 days). In the same days, ten random plants per plot were assessed for height with a ruler. On December 19, 2017 (32 DAE) we assessed weed infestation levels, and rice and soybean dry mass as function of treatment, by harvesting all plants into four quadrats with 0.5 m side in each plot. Rice and soybean grain yield were assessed at the end of the respective cropping cycles, in March and April 2018, when two samples of 4 $m^2$ per plot were harvested by hand and threshed, subjected to oven drying with forced air circulation at 65 ± 5 °C, after which the grains were weighed and their mass corrected to 13% humidity.

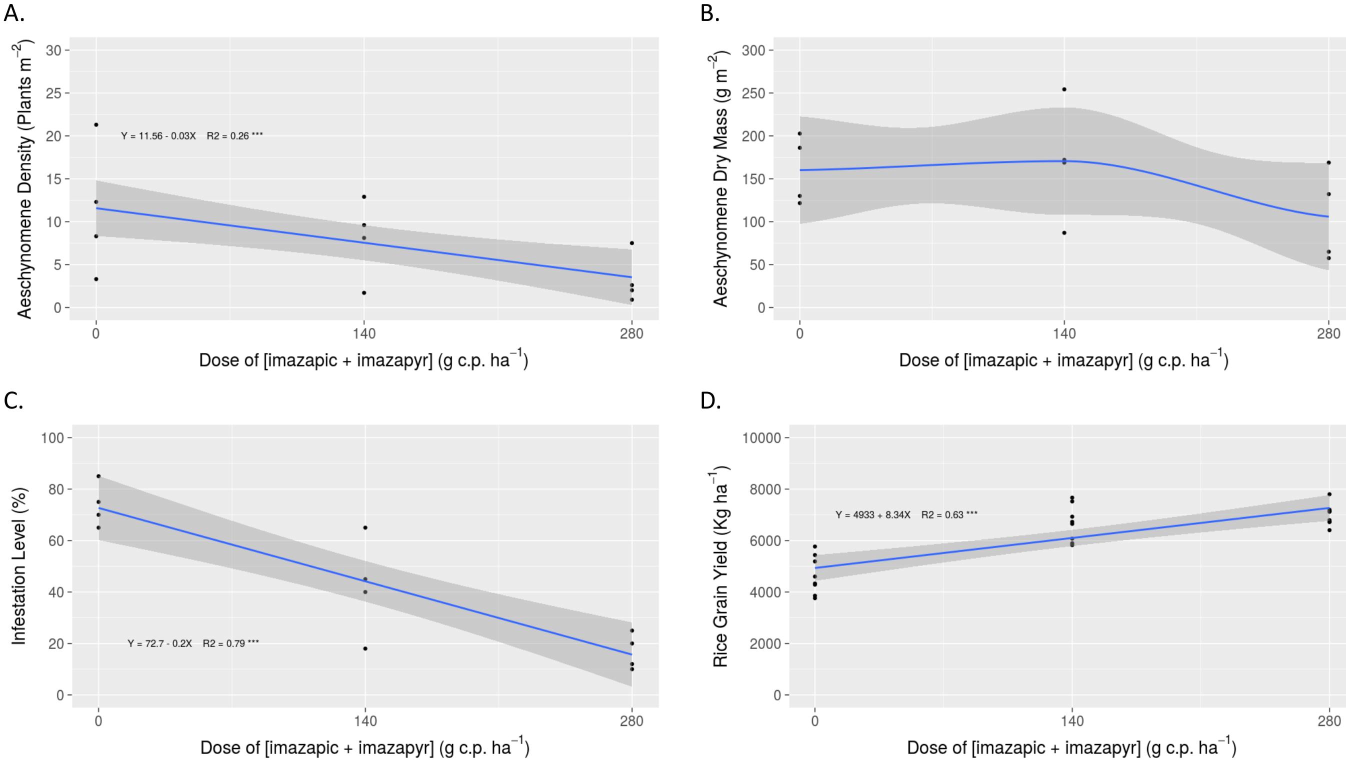
The data set was verified for typing errors, checked for normality and homogeneity and submitted to analysis of variance by the F-test at 5% probability to verify treatment effects. As the studied factor was quantitative, all variables were submitted to regression analysis. Those variables whose treatment effect was non-significant were modeled by using LOESS regression fit (Cleveland & Devlin, 1988); on the other side, those variables with significant treatment effects were modeled by using the 1st degree linear model, presenting also the adjustment coefficient and the regression significance level. For both cases, 95% confidence intervals for the regressions were presented. All analyzes were performed into the statistical environment "R" (R Core Team, 2021), using the packages ExpDes and ggplot2.

## Results and Discussion

### Effect on application crop (1st summer) and *Aeschynomene* spp. control efficiency

When Kifix® was applied on Clearfield® rice according to its technical indications, it promoted reductions on density and infestation of jointvetch as the dose was increased (Figure 1). While the control treatment (without herbicide application) presented 8-15, 5-10, and 1-7 plants $m^{-2}$ were observed for 140 and 280 g $ha^{-1}$ of Kifix®, respectively. This means that for every 35 g $ha^{-1}$ of Kifix®, the jointvetch infestation was reduced in one plant $m^{-2}$, or 10,000 plants $ha^{-1}$ (Figure 1A).

The overall infestation level (Figure 1C), however, decreased at a higher rate that jointvetch infestation level, evidencing that Kifix® is more efficient in controlling most other weed species present into the plots. While 60-82 weeds $m^{-2}$ were reported at




The significance of the effect by F-test, with 95% confidence intervals, are shown.

**Figure 1.** *Aeschynomene* density (plants $m^{-2}$) (A); *Aeschynomene* dry mass (g $m^{-2}$) (B); infestation level (%) (C), and rice grain yield (kg $ha^{-1}$) (D) based on dose of [imazapic + imazapyr] (g c.p. $ha^{1}$).

the control treatment, only about 4-30 plants $m^{-2}$ were reported when applying 280 g $ha^{-1}$ of Kifix®. This means that the expected weed control efficiency when applying Kifix® in conditions similar to the ones reported at the experiment, would be between 50 and 95% for most cases. On average, every 5 g $ha^{-1}$ of Kifix® promoted control of 10,000 weed plants $ha^{-1}$ (Figure 1C).

As consequence of the efficient weed control (Figures 1A and 1C) allied to the tolerance of the cultivar Guri INTA CL to Kifix®, the rice grain yield increased linearly with the dose of Kifix® (Figure 1D). The expected yield increased from 4,400-4,700 kg $ha^{-1}$ at the control treatment, to 6,950-7,850 kg $ha^{-1}$ at the higher Kifix® dose, meaning that every 1g of Kifix® promoted 8.34 kg $ha^{-1}$ of gains on productive terms (Figure 1D).

The interaction between improved weed control levels and gains in crop productivity is reported in several studies and for several crop species (Ottis & Talbert, 2007; Muhammad et al., 2016; Concenço et al., 2018; Martins et al., 2021), and the herbicide Kifix® seems to accomplish this task very well for several weed species traditionally reported in rice fields, independently of the irrigation method (Andres et al., 2017).

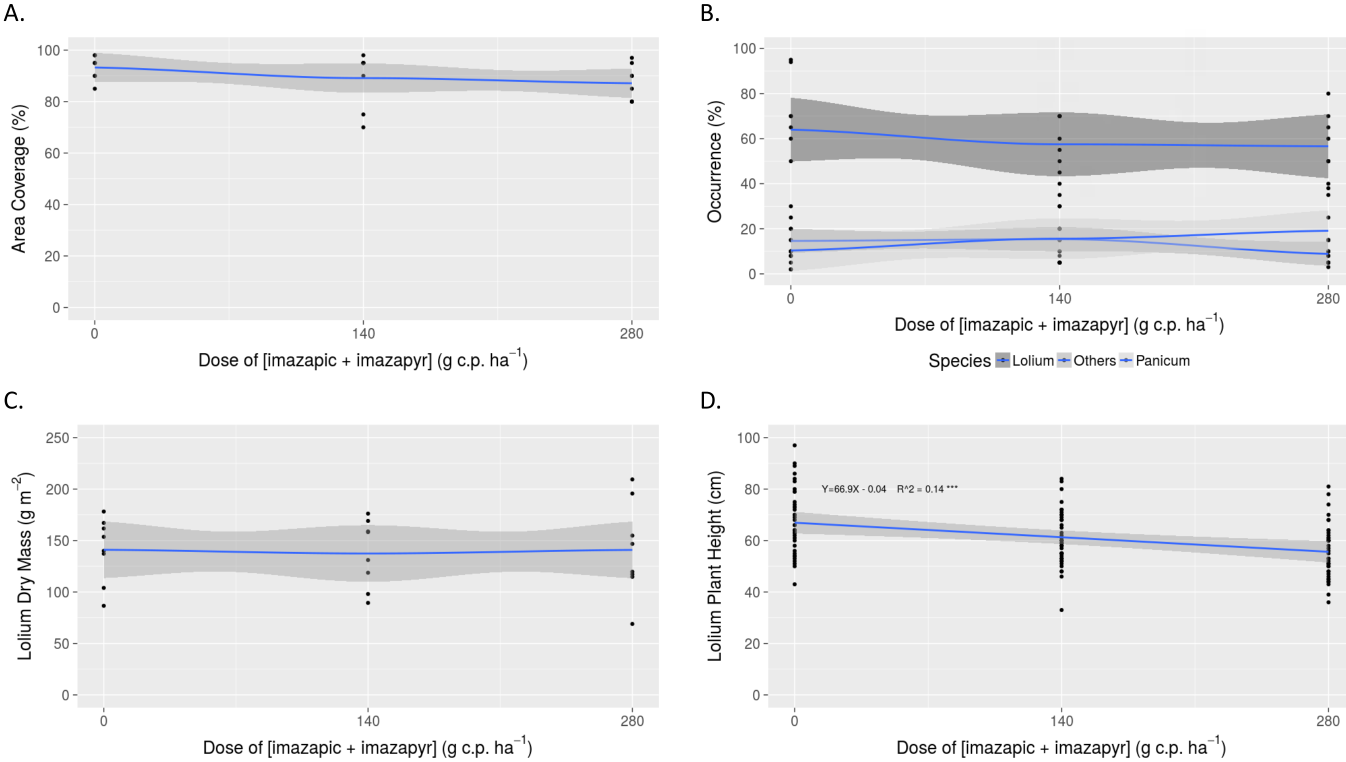
## Effect on winter culture

Ryegrass (*L. multiflorum*) cv. BRS Ponteio established relatively well (above 90% of emergence) in the whole experiment even with no fertilization other that the residual from the preceding rice crop, covering - together with other species present, about 90% of the area, independently of the treatment (Figure 2A).

This ability to homogeneously occupy the area is an important trait for plant species traditionally used as mulching during fallow periods (Lima Filho et al., 2014). In Rio Grande do Sul, Brazil, ryegrass is also used as forage for cattle feeding; part of the farmers use the fallow period to plant ryegrass, alone or associated to nitrogen-fixing forage species, to feed cattle between two summer cropping seasons, but it also may bring some problems as soil compaction or destruction of the levees used for rice irrigation (Goulart et al., 2020). In any case, the farmer should be aware that ryegrass may only be efficient in suppressing the proliferation of rice weed species during fallow if efficient soil cover is achieved (Figure 2A).

Even with well ryegrass establishment, there was significant weed infestation in germination gaps along the field (Figure 2B). *Panicum* sp. (a species of panic grass) was one of the main weeds observed in the fallow period, being one of the species with most potential to compete with ryegrass. During fallow, other weed species were rarely observed, being reported together as "others" (Figure 2B). From the 90% of area reported as occupied by vegetation (Figure 2A), about 50-70% was covered with ryegrass, and the remaining 20-40% was used by *Panicum* sp. and other rare weed species (Figure 2B).

Ryegrass dry mass (Figure 2C) was equal for all treatments, with approximately 140 g $m^{-2}$ (equivalent to 1,400 kg $ha^{-1}$); no clear influence of Kifix® on this variable was found. Plant height, on the other side, was affected by Kifix® doses and at the maximum dose, ryegrass plants were 4-16 cm lower than the observed at the control treatment (Figure 2D). Apparently,




The significance of the effect by F-test, with 95 % confidence intervals, are shown.

**Figure 2.** Area coverage (%) (g c.p. ha$^{1}$) (A), occurrence (%) (B); *Lolium* dry mass (C), and *Lolium* plant height (cm) (g c.p. ha$^{1}$) (D) based on dose of [imazapic + imazapyr].

this difference in plant height was fully compensated by ryegrass in dry mass accumulation (Figure 2C). This effect on ryegrass development is reported by Grey & Newsom (2016) when applying some ALS inhibiting herbicides for controlling wheat weeds pre-emergence.

Farmers in Southern Brazil often have complaints about poor ryegrass establishment and production in areas following Clearfield® rice. The lower plant height in these areas may lead farmers to this conclusion, but our data suggest that dry mass production is maintained, even with lower ryegrass plants.

## Effect on rice and soybean in rotation (2nd summer)

### *Rice*

The establishment of rice plants was not affected by Kifix® doses (Figure 3A), with emergence starting 5 DAS and stabilizing about 20 DAS at density of about 155 plants m$^{-2}$. This density is a little below the usually adopted for Rio Grande do Sul, which averages about 300-340 seeds m$^{-2}$ (Sosbai, 2018). However, Ottis & Talbert (2007) reported no difference in rice grain yield with rates between 57-500 seeds m$^{-2}$. No damage by possible residual effect of Kifix® application in the preceding year was observed on rice emergence curve (Figure 3A).

Plant height showed no significant variation within the assessed confidence interval (reduction from about 13 cm to about 11 cm) at 25 DAE (Figure 3B). The Kifix® does not seem to affect the initial establishment of non-Clearfield® rice planted one year after its application in lowland areas of Southern Brazil.

Weed infestation was assessed 32 DAE (Figure 3C); although there was a clear tendency of reduced weed occurrence as the dose of Kifix®, applied in the previous year, increased, this was not significant according to the F-test, as well as the confidence intervals. It is hypothesized that the residual effect of Kifix® in the first cropping season (Clearfield® rice) inhibited weed seeds production and resulted in a tendency for lower infestation levels in the subsequent crop (Norsworthy et al., 2016), although the confidence intervals report it as non-effective (Figure 3C).

At the same time (32 DAE), rice dry mass was assessed and also no difference was reported as function of treatments, with about 16-22 g m$^{-2}$ of dry mass (Figure 3D). At the end of the crop cycle, in March 2018, rice grain yields were also consistent among treatments with 7,200-8,800 kg ha$^{-1}$ of grains (Figure 3E).

### *Soybean*

The establishment of soybean plants was barely affected by Kifix® doses (Figure 4A), with emergence starting five DAS and stabilizing about 20 DAS at density of about 25 plants m$^{-2}$. This density represents about 250,000 plants m$^{-2}$, which is recommended for the variety and the sowing regions where the experiment was installed (Emygdio et al., 2017). A small treatment effect is observed, where about 30 plants m$^{-2}$ were reported at the control treatment, being reduced to about 24 plants m$^{-2}$ at dose of 280 g ha$^{-1}$ (Figure 4A). When considering the natural variation of the data, however, it should be inferred that this effect should be confirmed by future studies.

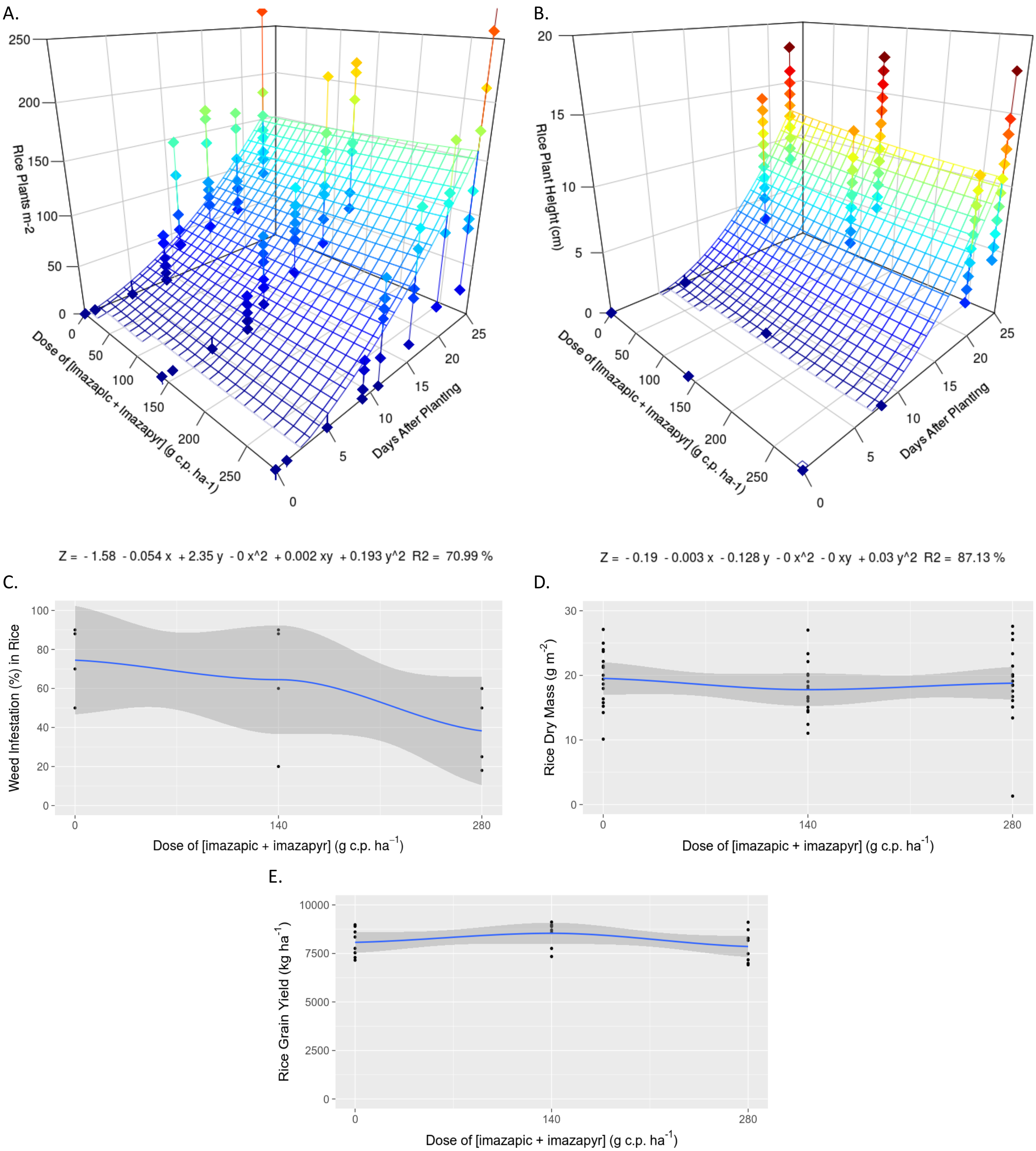



**Figure 3.** Curve of rice plants cv. BRS Pampa as a function of days after sowing and Kifix® (Imazapic + Imazapyr) doses (A), plant height curve of rice plants cv. BRS Pampa (B), weed infestation (C), rice dry mass (D), and rice grain yield (E) as function (Imazapic + Imazapyr) doses.

Plant height was not affected, measuring about 13 cm, 25 DAE (Figure 4B). Kifix® does not seem to affect, at considerable extent, the initial establishment of soybean, planted one year after its application in lowland areas of Southern Brazil.

It should be mentioned also that the experimental area, during winter - when ryegrass was being grown, was submitted to heavy and frequent rainfall events (Figure 5), which promoted various short-term flooding intervals; thus, the area was most of the time wet or flooded prior to sowing soybean and rice. In environments like this (frequent hypoxia), degradation of ALS-inhibiting herbicides is supposed to be delayed and to occur at lower rates (Avila et al., 2021).

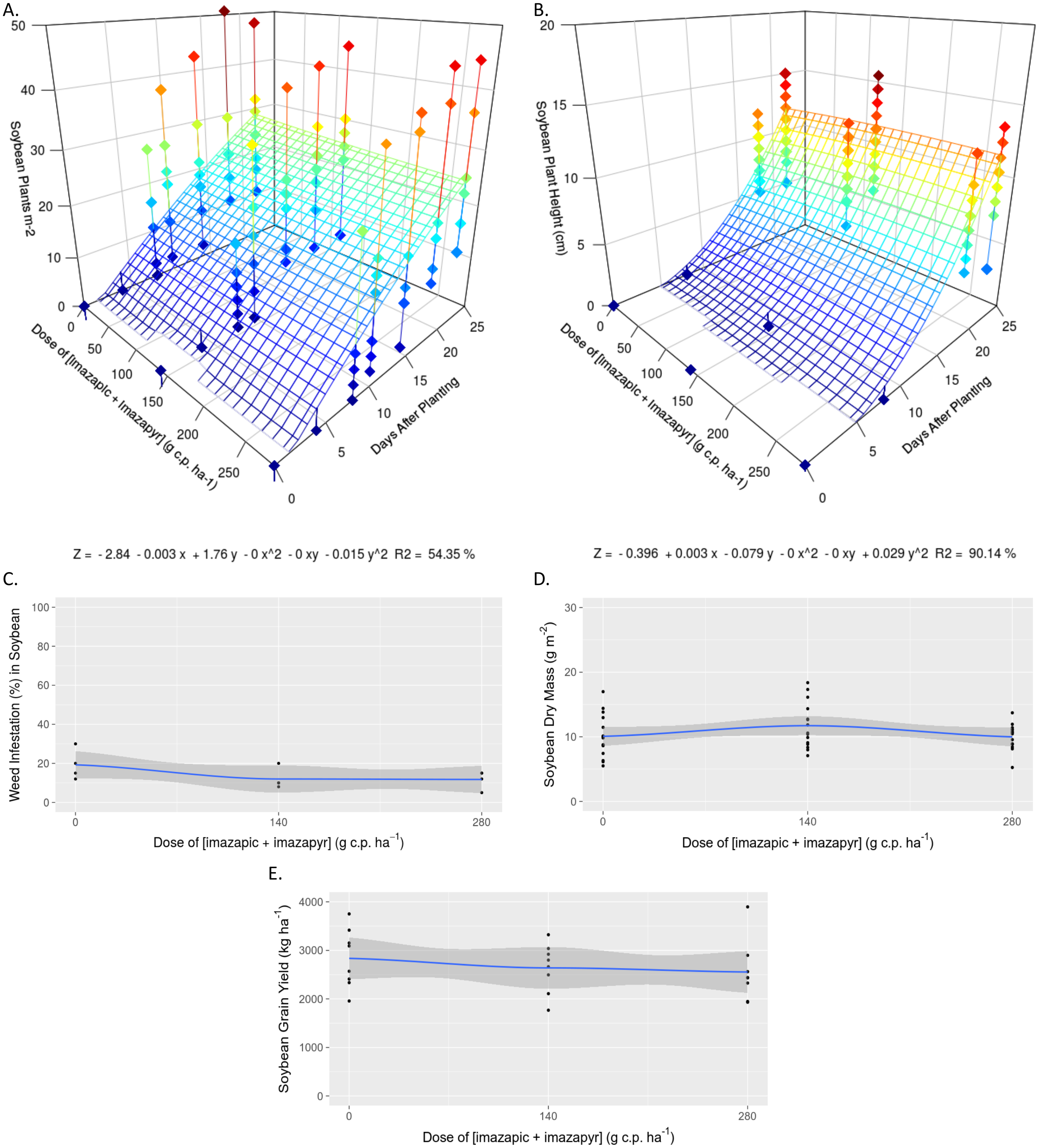



**Figure 4.** Curve of soybean plants cv. BMX Ponta iPro as a function of days after sowing and Kifix® (Imazapic + Imazapyr) doses (A), plant height (B), weed infestation (C), soybean dry mass (D), and soybean grain yield (E).

Weed infestation was assessed 32 DAE (Figure 4C); although there was a small tendency of reduced weed occurrence as the dose of Kifix®, applied in the previous year, increased, this was not significant according to the F-test, as well as the confidence intervals. The hypothesis for this is the same discussed for the rice areas (Norsworthy et al., 2016) (Figure 4C).

At the same time (32 DAE), soybean dry mass was assessed and also no difference was reported as function of treatments, with about 9-12 g m$^{-2}$ of dry mass (Figure 4D). At the end of the crop cycle, in April 2018, soybean grain yields were also consistent among treatments with expected yields between 2,300-3,100 kg ha$^{-1}$ of grains (Figure 4E), according to the 95 % confidence interval.

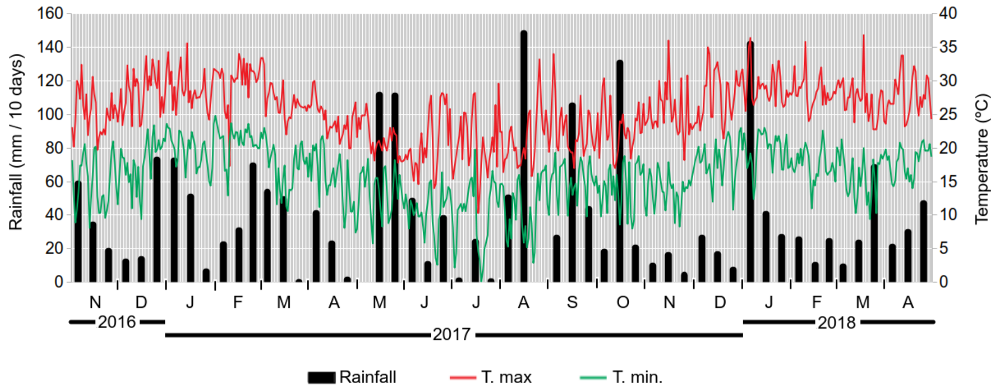



**Figure 5.** Rainfall events and temperature in experimental area, during winter, in 2016, 2017, and 2018 respectively.

The subject discussed in the present experiment - impact of ALS inhibitor herbicides associated to Clearfield® technology on succeeding crops, is studied by some researchers in slightly different edapho-climatic conditions. In a study similar to the present one, but installed under controlled environment (lysimeters), Bundt et al. (2015) reported no visual symptoms of intoxication to ryegrass, but some reduction in dry mass when this species was planted 128 DAA of Kifix®; the same authors reported damages to rice planted on the succeeding summer (1 year after application) of about 70% in rice dry mass, compared to the control treatment with no application.

Regarding herbicide degradation, soil moisture is preponderant (Azcarate et al., 2015); in our study, the winter period - when ryegrass is grown, was predominantly humid (Figure 5), with 222, 97, 26, 199, 175, and 169 mm of rains, respectively for May, June, July, August, September, and October 2017 (approximately 4.85 mm day$^{-1}$). It should be highlighted that, in the same time interval the mean daily evapotranspiration (ET) rates were about 1.6 mm day$^{-1}$, proving that it was a rainy and humid winter on average.

Santos et al. (2014) also conducted a similar experiment, under greenhouse using plastic boxes with 36 kg of soil per plot. These authors reported that ryegrass planted in succession to Clearfield® rice, as well as rice varieties IRGA 424 and BRS Querencia planted one year later, are susceptible to Kifix®. The authors reported that ryegrass shoot dry mass and plant height were reduced, respectively, by 65 and 44%, compared to the respective control treatment with no herbicide residuals. For rice, shoot dry mass and plant height were reduced, respectively, by 60 and 50% (mean of IRGA 424 and BRS Querencia).

Several studies regarding the problematics of the effects of Kifix® on succeeding crops are conducted under controlled environments. However, Schreiber et al. (2018) reports that the residual activity of soil-applied herbicides depends heavily on edapho-climatic variables, as soil profile depth (Bundt et al., 2015), texture, permeability (Schreiber et al., 2018), clay content, moisture (Azcarate et al., 2015), rainfall, and several other aspects. Most studies conducted under controlled environments may simply not have enough soil profile into the plot for the herbicide to dissipate, since as deeper the soil profile, as weaker the Kifix® carryover to succeeding crops (Bundt et al., 2015).

As the environmental herbicide dynamics is greatly influenced by edapho-climatic conditions, studies under controlled environments do not seem to be the best way to make reliable inferences about the subject. Under field conditions, rainfall amount and frequence, run-off processes, temperature variation range, presence of spontaneous plant species and even the soil microbiote activity (Coleman et al., 2017) are completely different compared to the observed under controlled conditions. Poorter et al. (2016) reported only a modest average correlation of about 26% between experiments installed under controlled environments and their respective replications under field conditions.

Pinto et al. (2009), working under field conditions with the herbicide Only® (imazethapyr 75 g L$^{-1}$ + imazapic 25 g L$^{-1}$), predecessor of Kifix® on the Clearfield® technology, reported that ryegrass can be planted 180 DAA of Only®; before this time interval, there are significant damages to plant growth and development in the edapho-climatic conditions of Rio Grande do Sul, Brazil. Furthermore, the same authors report that in regions with sandy soil, associated to dry and cold winters, the herbicide Only® could accumulate in soil following successive applications (1 or 2 per year), and on the long-term cause intense damages no either ryegrass on non-Clearfield® rice.

## Additional remarks

It seems to be clear that Kifix®, applied to Clearfield® rice, still show signs of its presence in soil both on mulching species planted in succession, as well as on non-Clearfield® rice and soybean planted on the following cropping season (~1 year after Kifix® application), as reported in Figures 2, 3, and 4. In the present study, however, these effects were discrete and observed both on initial crop plants development as well as on weed establishment, with no impact on rice or soybean grains yield (Figures 3E and 4E, respectively). It can be inferred that the herbicide Kifix® (imazapic + imazapyr), would most probably cause damages to these crops only in edaphoclimatic conditions causing limited degradation rates along the time.

Furthermore, the results of the F-test and confidence intervals, respectively at 5% probability and 95% confidence, were consistent for all cases; this is due to (1) our data set seems to be consistent enough for the inferences (sufficient statistical power), and (2) significance levels (both for those significant results as well as for the non-significant ones) seem to be far from the surrounding edges of the 5% probability to avoid statistical fallacy (Reinhart, 2015) which constitutes statistical error in hypothesis acceptance or rejection caused by limitations of the statistical method when the probability levels are close to the threshold established for the statistical test applied.

## Conclusions

Our experiment reported mild damages from Kifix® residues on soil in ryegrass planted in succession to Clearfield® rice, as well as on non-Clearfield® rice planted in rotation to Clearfield® rice, under lowland areas of Southern Brazil. The damages long-term of Kifix® doses in soybean plants does not seem to affect, in large-scale, the initial establishment of soybean, sowed one year after its application in lowland areas of Southern Brazil.

The control efficiency of jointvetch was enhanced with increasing Kifix® dose, possibly due to the residual effect of Kifix® from the first growing season with Clearfield® rice, reflected in a lower weed infestation and seed production. However, the continuous use of these herbicides should be carried out cautiously, in order to, among other factors, minimize the selection pressure of resistant weeds.

Furthermore, the possibility of accumulation of Kifix® residues in soil, after repeated applications of Kifix®, should be verified in further studies.

## Compliance with Ethical Standards

**Author contributions:** Conceptualization: GC, AA; Data curation: GC, LBXS, TSM, ADSC, CSS; Formal analysis: GC, AA; Funding acquisition: GC, AA; Investigation: GC, LBXS, TSM, ADSC, CSS. Methodology: GC, AA; Project administration: GC, AA; Resources: GC, AA; Software: GC; Supervision: GC, AA; Validation: GC, LBXS, TSM; Visualization: GC, LBXS, TSM, ADSC, CSS; Writing - original draft: GC, LBXS, TSM, ADSC, CSS; Writing - review & editing: GC, AA.

**Conflict of interest:** All authors declare that there are no personal or professional conflicts of interest.

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