



## Cropping systems on root rot and soybean seed yield

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**ABSTRACT:** Root rot (RR), which can occur in different cropping systems, affects soybean seed yield. The aim of this study was to determine the incidence of RR in soybean crop systems and its relationship with soybean yield. The study was carried out for two growing seasons in a no-till system consisting of four soybean crop systems: soybean-oat+soybean-oat, soybean-maize+soybean-maize, soybean-wheat+soybean-wheat and soybean-pasture+soybean-pasture. Data were submitted to Pearson's correlation. Incidence of RR, mainly charcoal rot and sudden death, was more than 50% in soybean roots for all the soybean crop systems and consequently decreased yield by around 22kg ha<sup>-1</sup> of seed for every 1% increase in RR. Root rot led to a decline in seed yield from 20 to 102kg ha<sup>-1</sup> in the first season and 9 to 32kg ha<sup>-1</sup> in the second season, considering all the cropping systems. Soybean + pasture was the lowest productive system, with a negative RR impact of 74.9 and 32.9kg ha<sup>-1</sup> in the first and second season, respectively.

**Key words:** *Glycine max*, root diseases, yield, root healthy, *Macrophomina*, *Fusarium*.

### Sistemas de cultivo afetam podridões radiculares e produtividade de semente de soja

**RESUMO:** As podridões radiculares podem ocorrer em diferentes sistemas de cultivos e afetar a produtividade. Objetivou-se neste trabalho quantificar a incidência de podridões radiculares em distintos sistemas de sucessão de cultivos e sua relação com a produtividade de sementes de soja. A pesquisa foi realizada por duas safras agrícolas, na Região de Ponte Serrada, Santa Catarina, em lavouras de sementes de soja cultivadas em plantio direto que foi subdividida em quatro sistemas de sucessão de cultivos: aveia-soja+aveia-soja, milho-soja+milho-soja, trigo-soja+trigo-soja e pasto-soja+pasto-soja. Os dados foram submetidos à correlação de Pearson e ao teste de médias de Duncan ou F ( $P < 0,05$ ). Constatou-se que a incidência de podridões radiculares, principalmente podridão cinzenta e morte súbita, na média dos sistemas, está acima de 50% e como consequência gerou redução de produtividade na ordem de 22kg ha<sup>-1</sup> de semente de soja para cada 1% de aumento na incidência destas doenças. As podridões radiculares reduzem a produtividade de 20 a 102kg ha<sup>-1</sup> na primeira safra e, de 9 a 32kg ha<sup>-1</sup> na segunda safra, considerando todos os sistemas de cultivo. O sistema soja+pasto, é o menos produtivo com impacto negativo das PR de 74,9 e 32,9kg ha<sup>-1</sup> na primeira e segunda safra, respectivamente.

**Palavras-chave:** *Glycine max*, doenças radiculares, desempenho agrônomico, *Macrophomina*, *Fusarium*.

## INTRODUCTION

Soybean is the most widely grown oil seed in the world, covering 150 million hectares and accounting for production of 345 million metric tons (t). This economically important grain, used for human consumption, oil production, animal feed and fuel, is Brazil's most exported agricultural product (CONAB, 2017a).

In the 2016/2017 growing season, the soybean cultivated area was approximately 34 of million hectares, producing 114 million t with grain yield of 3364kg ha<sup>-1</sup> (CONAB, 2017b) and requiring around 2.1 million t of seeds (CONAB, 2017b; ABRASEM, 2018). In order to increase yield,

continuous investment in modern soil management technologies, liming, fertilization, and seeding, associated with efficient weed, pest and disease control is needed (THOMAS & COSTA, 2010; FREITAS, 2011), in addition to suitable crop rotation. Expansion of soybean growing area has prompted an increase in monoculture farming (PEREZ-BRANDAN et al., 2014); thereby, raising the occurrence and intensity of diseases. All parts of the soybean plant are susceptible to plant pathogens (HARTMAN et al., 1999), especially fungus-related diseases associated with root rot (RR) (HENNING, 2009).

Root rot fungi are natural soil inhabitants that survive on soybean crop remnants on the soil surface, particularly in a no-till system (PEREZ-

BRANDAN et al., 2014; KLINGELFUSS et al., 2007). Root rot and early plant death (COSTAMILAN, 1999; SARR et al., 2014) affect pod filling, resulting in small, green or deteriorated seeds that compromise seed lot quality and reduce crop yield (SHADAKSHARI et al., 2014). Among the main fungal species are *Macrophomina phaseolina* (Tassi) Giodanish and *Fusarium solani* (Mart.) Sacc.

*M. phaseolina* are found in large numbers on plant hosts such as soybean, common beans, peanuts, cotton, sunflower, castor beans and maize (GUPTA et al., 2012; SARR et al., 2014). Tissue infection and colonization may occur in young plants; although symptoms such as charcoal or grey soybean root or stem rot are more visible in the reproductive phase. Plants grown in compacted soils, periods with no rainfall, nutritional imbalance and high temperatures are more susceptible to the disease (GUPTA et al., 2012; SARR et al., 2014). Managing RR requires preventive measures such as crop rotation, use of less vulnerable cultivars, seeding planning (to minimize plant exposure to periods of drought), maintaining soil moisture (to avoid water stress), avoiding excessive plant density in soybean crop (GUPTA et al., 2012; SARR et al., 2014).

For *F. solani* fungus the symptoms are named sudden death syndrome (SDS), which are influenced by the environment, seeding time, soil homogeneity, temperature and moisture content, air temperature and amount of inoculum in the soil (KLINGELFUSS et al., 2007).

In Brazil, there is scarce information on occurrence of RR in seed production systems or chemical control of RR applying fungicides. Soil decompaction, scarification and subsoiling improve root development conditions; thereby, decreasing the susceptibility of plants to RR, and crop rotation contributes to hampering the survival of these RR fungi (HENNING, 2009).

The aim of this study was to assess management methods (crop systems), RR incidence and prevalence of *Macrophomina* and *Fusarium* at early (R2) and late (R8) stages of soybean development for two consecutive growing seasons, in addition to the determining the correlation between seed yield and management methods.

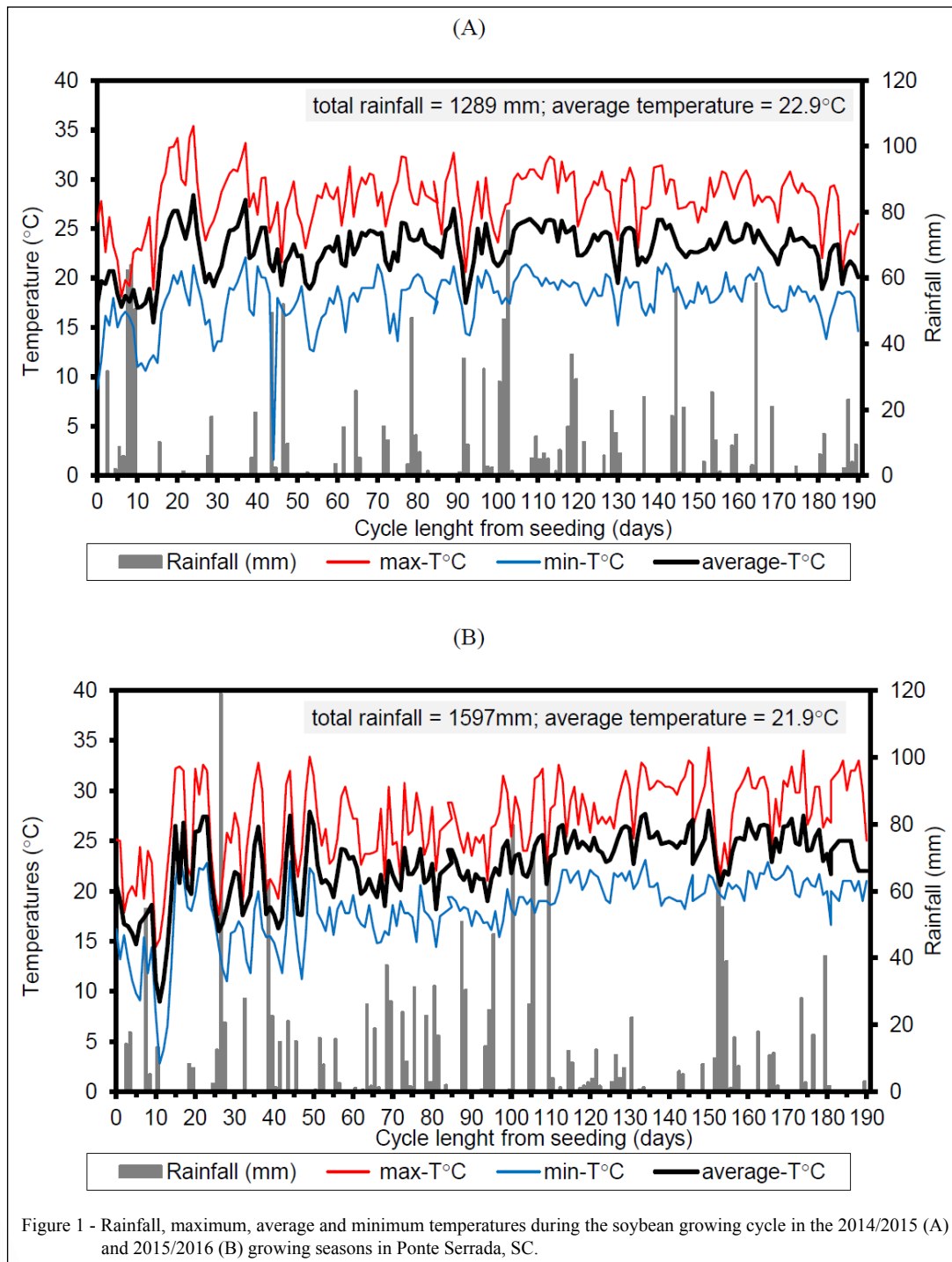
## MATERIALS AND METHODS

The study was conducted in Ponte Serrada, Santa Catarina during the 2014/2015 and 2015/2016 growing seasons, with average temperatures of 22.9 and 21.9°C, respectively; with total rainfall of 1289

and 1594mm in first e second season, respectively (Figure 1) (INMET, 2016). Soil in the experimental area is classified as predominantly typical nitisol (red-yellow podzolic with clay texture); the 0-20cm layer contained an average of 322g kg<sup>-1</sup> of clay; 35g kg<sup>-1</sup> of organic matter; water pH of 5.2; 10mg dm<sup>-3</sup> of P; 142.4mg dm<sup>-3</sup> of exchangeable K (Mehlich 1 extractant); 8.3cmolc dm<sup>-3</sup> of exchangeable Ca and 3.4cmolc dm<sup>-3</sup> of exchangeable Mg (KCl 1mol L<sup>-1</sup> of extractor). Soybean seeding of cultivar NS4823 was performed every year in the second half of October for a population of 22 plants m<sup>-2</sup>. Fertilization and crop treatments were applied in each growing season to achieve soybean seed yield potential of 5t ha<sup>-1</sup> using soybean growing recommendations, in a similar manner described by SOUZA et al. (2013).

Cropping systems follow a seeding sequence in the same area: i) soybean+oat (oat+soybean+oat+soybean) identified by the following geodesic coordinates: latitude 26°52'S; longitude 52°01'W; altitude 995m; ii) soybean+maize (maize+fallow+soybean+fallow+maize+fallow+soybean) (26°51' S; 52°02' W; 1071m), iii) soybean+wheat (wheat+soybean+wheat+soybean) (26°49' S; 52°01' W; 846m) and iv) soybean+pasture (pasture+soybean+pasture+soybean) (26°56' S; 52°02' W; 1057m); the winter pasture of this cropping system consists of a mixed black oat with ryegrass. Four treatments were established for each cropping system: T1 - plants with no early symptoms of root rot - RR; T2 - plants with early symptoms of RR, consisting of smaller shoots and visible inner tissue discoloring (observed with the help of a penknife) in the hypocotyl region (*Macrophomina*, charcoal or grey rot and *Fusarium* by the pinkish color); T3 - plants with no late symptoms of RR; and T4 - plants with late symptoms of RR. Early RR symptoms were assessed and characterized in plants at reproductive stage R2 (full bloom) and the late symptoms of RR in stage R8 plants (crop maturity). All treatments were geodetically demarcated using a GPS device (GPS Map Garmin) on 1/18/2015 for the 2014/2015 crop and the same coordinates were used for the 2015/2016 growing season. Geo referencing was necessary to assess each treatment at two growth stages and two growing seasons. Each treatment was identified and predefined as a crop area of more than 100m<sup>2</sup> and 50 meters apart. The experimental units within each treatment consisted of 5 rows measuring 5m long.

When plants reached stage R8 (crop maturity, complete defoliation and all pods with yellow-straw coloration), they were evaluated for RR incidence, as follows: plants with no visible symptoms of RR were



separated from their symptomatic counterparts (only for *Macrophomina* or *Fusarium*). This assessment was made in all the plants collected along 5-meter-long rows, totaling five repetitions per treatment.

The RR incidence was obtained by dividing the number of plants with RR by the number of plants

sampled and multiplying the result by 100. Predominance was obtained by dividing the number of plants with *Macrophomina* by the number of plants with RR and multiplying the value obtained by 100, and dividing the number of plants with *Fusarium* by the number of plants with RR and multiplying the result by 100.

Yield was obtained by manually harvesting of all the plants in the 5-meter rows of each repetition and each treatment. Next, manual threshing was performed and seed yield was estimated in kg ha<sup>-1</sup>, corrected for standard moisture of 13%. Corrected weight was obtained by the following equation:

$$CW = SY_{plot} * \left[ \frac{100 - RM}{100 - 13} \right]$$

, where CW is corrected weight; SY<sub>plot</sub> is a yield of each plot; RM is the real moisture of seeds at harvest and 13 the standard moisture content of 13%. Real moisture was obtained by heating in an oven at 80°C until reaching constant weight, starting from initial moisture of 100g of pure seeds. To calculate moisture content, expressed in moist weight, the following equation was used:

$$M\% = 100 * \left[ \frac{MW - DW}{MW} \right]$$

M% is moisture content, MW is moist weight of seeds and DW is dry weight of seeds. This study used a random block design in each cropping system. Cropping system and respective treatments per system were considered a fixed effect and the growing season random effect. Results were analyzed using the F-test and mean separation by Duncan's test to compare treatments within each cropping system and between systems. For comparisons between healthy and unhealthy plants or between growing seasons, the F-test was conclusive. Cropping systems and growing seasons were jointly analyzed as environmental effects. Pearson's correlation coefficient was applied as follows: (i) general correlation was performed for each growing season and (ii) specific correlation for each cropping system, in each soybean growing season. These correlations were based on seed yield (SY) correlated with root rot (RR) incidence. A 5% significance level was set for all analyses. Statistical analysis was carried out using SAS software, version 9.2.

## RESULTS AND DISCUSSION

Seed yield (SY) showed a significant difference from one growing season to another, between cropping systems and between treatments (Table 1). In the first growing season, in the soybean + oat cropping system, SY was significantly higher in treatments T1, T2 and T3, with 1942, 1916 and 2008kg ha<sup>-1</sup> respectively, when compared to plants with symptoms of late RR (T4), where SY was only 1850kg ha<sup>-1</sup> (Table 1). In the second season, plants with both early and late RR symptoms (T2, 2463 and T4, 2235kg ha<sup>-1</sup>) exhibited significant declines in relation to symptom-free plants (T1, 2633 and T3, 2761kg ha<sup>-1</sup>), respectively (P<0.05; Table 1).

In the soybean + maize cropping system, plants with early or late symptoms of RR (T2, 1906 or T4, 1862kg ha<sup>-1</sup>) were less productive than their symptom-free counterparts (T1, 2105 and T3, 2148kg ha<sup>-1</sup>; P<0.05; Table 1) and in the second season, T1, T2 and T3 produced 2300; 2265 and 2491kg ha<sup>-1</sup>, respectively, with significantly higher SY than that obtained in plants with late RR symptoms (T4), which produced only 2075kg ha<sup>-1</sup> (P<0.05; Table 1).

The soybean+wheat cropping system with RR symptoms (early or late) showed significantly lower SY (T2, 2001 or T4, 1940kg ha<sup>-1</sup>) compared to plants with no RR symptoms (T1, 2117 and T3, 2178kg ha<sup>-1</sup>) and in the second season, behavior was statistically equal, but the yields in plants with RR symptoms were T2, 1365 and T4, 1347kg ha<sup>-1</sup>, and those free of symptoms (early or late) T1, 1417 and T3, 1435kg ha<sup>-1</sup> (P<0.05; Table 1).

In general, the soybean+pasture cropping system was less productive, and plants with early or late RR symptoms (T2, 1263 and T4, 1271kg ha<sup>-1</sup>) produced statistically less compared to those with no RR symptoms (T1, 1409 and T3, 1401kg ha<sup>-1</sup>). Behavior differed in the second season, with yields of T1, 1500; T2, 1448 and T3, 1607kg ha<sup>-1</sup>, higher than those of T4 (late symptoms of RR) with only 1343kg ha<sup>-1</sup> (P<0.05; Table 1). In summary, the SY of plants with early or late symptoms of RR was significantly lower (P<0.05) compared to plants with no RR symptoms, in both seasons and cropping systems (Table 1).

Considering the effect of cropping system in the first season, the soybean+oat, soybean+maize and soybean+wheat systems were more productive than the soybean+pasture system (1929, 2005 and 2059kg ha<sup>-1</sup>, versus 1336kg ha<sup>-1</sup>; Table 1). In the second season, the most productive cropping system was soybean+oat (2458kg ha<sup>-1</sup>), followed by soybean+maize (2283kg ha<sup>-1</sup>), while soybean+wheat and soybean+pasture were once again the lowest productive, with 1391 and 1475kg ha<sup>-1</sup>, respectively (P<0.05; Table 1).

Considering only plants with and without late RR symptoms (T3xT4), seed yields increased significantly when only healthy plants were assessed in the soybean+oat, soybean+maize and soybean+wheat systems, obtaining SY of 2008, 2148 and 2178kg ha<sup>-1</sup>, respectively, while the soybean+pasture system produced only 1401kg ha<sup>-1</sup> (P<0.05; Table 1). In unhealthy plants, SY were 1850, 1862 and 1940kg ha<sup>-1</sup> in the soybean+oat, soybean+maize and soybean+wheat systems and once again the soybean+pasture system exhibited the lowest SY, with only 1271kg ha<sup>-1</sup> (P<0.05; Table 1).

Table 1 - Soybean seed yield as a function of different cropping systems, root rot and growing seasons in Ponte Serrada, Santa Catarina (SC), Brazil.

-----Cropping systems, treatments and growing seasons-----				
Systems	Treat	2014/2015	2015/2016	
-----kg ha <sup>-1</sup> -----				
Soybean+oat	T1	b 1942 A <sup>1</sup>	<sup>2</sup> /a 2633 A	
	T2	b 1916 A	a 2463 B	
	T3	b 2008 A	a 2761 A	
	T4	b 1850 B	a 2335 C	
Soybean+maize	T1	a 2105 A	a 2300 A	
	T2	b 1906 B	a 2265 A	
	T3	b 2148 A	a 2491 A	
	T4	b 1862 B	b 2075 B	
Soybean+wheat	T1	a 2117 A	b 1417 A	
	T2	a 2001 B	b 1365 B	
	T3	a 2178 A	b 1435 A	
	T4	a 1940 B	b 1347 B	
Soybean+pasture	T1	a 1409 A	a 1500 A	
	T2	a 1263 B	b 1448 A	
	T3	b 1401 A	a 1607 A	
	T4	a 1271 B	a 1343 B	
-----System comparison by growing season-----				
		2014/2015	2015/2016	
Soybean+oat		b 1929 A	a 2548 A	
Soybean+maize		b 2005 A	a 2283 B	
Soybean+wheat		a 2059 A	b 1391 C	
Soybean+pasture		b 1336 B	a 1475 C	
-----Healthy x Unhealthy plants-----				
		Healthy	Unhealthy	≠ kg ha <sup>-1</sup>
-----2014/2015 Growing season-----				
Soybean+oat		a 2008 A	a 1850 A	158
Soybean+maize		a 2148 A	b 1862 A	286
Soybean+wheat		a 2178 A	b 1940 A	238
Soybean+pasture		a 1401 B	a 1271 B	130
-----2015/2016 Growing season-----				
Soybean+oat		a 2761 A	b 2335 A	426
Soybean+maize		a 2491 A	b 2075 A	416
Soybean+wheat		a 1435 B	b 1347 B	88
Soybean+pasture		a 1607 B	b 1343 B	264
CV%		17.2	20.1	

<sup>1</sup>Means followed by the same upper case letter in the column do not differ according to Duncan's test, at 5% probability. <sup>2</sup>Means preceded by the same lower letter on the line (growing season comparison) do not differ according to the F-test at 5% probability. Treat - treatments: T1 – plants with no early root rot symptom – RR (stage R2); T2 – plants with early RR symptoms; T3 – plants with no late RR symptoms (stage R8) and T4 – plants with late RR symptoms.

Differences in yields between healthy and unhealthy plants ranged from 130 to 286kg ha<sup>-1</sup>, equivalent to a difference of 2.2 to 4.8bags ha<sup>-1</sup> (1 bag corresponds to 60kg) in relation to RR.

In the second season, T3xT4 confirmed that the highest yields are obtained from healthy plants. Seed yield differences between healthy and

unhealthy plants ranged from 426, 416, 88 and 264kg ha<sup>-1</sup>, equivalent to 7.1, 6.9, 1.5 and 4.4 bags ha<sup>-1</sup> respectively, for soybean+oat, soybean+maize, soybean+wheat and soybean+pasture cropping systems (Table 1).

The soybean main yield components are the number of plants per ha<sup>-1</sup>, number of pods per

plant, number of seeds per pod and 1000-seed weight (THOMAS & COSTA, 2010). To achieve high yields, good crop management is necessary to obtain the maximum output of each component (THOMAS & COSTA, 2010; SOUZA et al., 2013). However, in relation to RR, when plants are symptomatic they die, form dead patches or yellow leaves and later drooping branches, on which leaves wilt, dry out and stick to the stems, resulting in deformed seeds and pods (GUPTA et al., 2012; KLINGELFUSS et al., 2007). CRUCIOL & COSTA (2017) evaluated two soybean cultivars artificially inoculated with RR dead patches and reported damage in 3.6% of the final production, representing losses of 2.2bags ha<sup>-1</sup>. This damage was similar to that observed in our research, varying from 2.2 to 4.8bags ha<sup>-1</sup> in the first season and 1.5 to 7.1bags ha<sup>-1</sup> in the second (Table 1).

With respect to RR incidence for the 2014/2015 season, a significant difference was reported between cropping systems, with the soybean+oat and soybean+maize systems obtaining lower RR incidence (Table 2). For the 2015/2016 season, the soybean+maize system exhibited the lowest RR values (about 20% lower; Table 2). This result may be due to the effect of monoculture.

Predominance of RR by etiologic agent in the first season, irrespective of cropping system,

showed 75% *Macrophomina* and 25% *Fusarium* (Table 2). In the second season, the incidence of *Macrophomina* was higher than that observed in the first season (96.9%). Also, in the second season, particularly the soybean+oat system showed the lowest *Fusarium* predominance (3.1%) than others (Table 2). Greater predominance of grey rot in the second season may be due to the lower rainfall observed between 130 and 150 days of the cycle (Figure 1B versus 1A) in addition to the fact that the fungus is a natural soil inhabitant. Another possibility is that the presence of soybean plant residues, particularly in the soil, increases propagation capacity via *Macrophomina* microsclerotia (REIS et al., 2014).

In Ponte Serrada, agricultural zoning indicates seeding time among Julian days from 290 to 360, whose seeding dates are between October 11 and December 31 (BRASIL, 2016). However, farmers prefer to seeding from 300 to 320 Julian days, avoiding early and latter days, because the soybean crop at this time is less affected by disease compared to the end of the recommended period (days 330 to 360), when the amount of disease inoculum available may be higher and would potentially increase the incidence and predominance of diseases such as RR.

The overall average of all the systems showed a decline of 23.0 and 22.6kg ha<sup>-1</sup> in SY per 1%

Table 2 - Incidence and predominance of root rot in soybean plants as a function of different cropping systems in two growing seasons in Ponte Serrada, SC.

-----Incidence of Root Rot-----				
Cropping systems	2014/2015 Growing season		2015/2016 Growing season	
	----- % -----			
Soybean+oat	a 60.0 B <sup>1</sup>		<sup>2</sup> a 54.7 A	
Soybean+maize	a 50.4 B		a 46.1 B	
Soybean+wheat	a 72.5 A		b 52.0 A	
Soybean+pasture	a 74.9 A		b 58.7 A	
CV%	13.5		28.4	
-----Predominant root rot fungi-----				
	----- <i>Macrophomina</i> -----		----- <i>Fusarium</i> -----	
	2014/2015 Season	2015/2016 Season	2014/2015 Season	2015/2016 Season
	----- % -----			
Soybean+oat	b 71.5 ns	a 96.9 A	a 28.5 ns	b 3.1 B
Soybean+maize	b 73.7	a 88.8 AB	a 26.3	b 11.2 A
Soybean+wheat	b 79.0	a 88.9 AB	a 21.0	b 11.1 A
Soybean+pasture	b 75.8	a 81.7 B	a 24.2	b 18.4 A
Mean	<sup>3</sup> a 75.0		b 25.0	
CV%	9.5	8.4	28.6	7.11

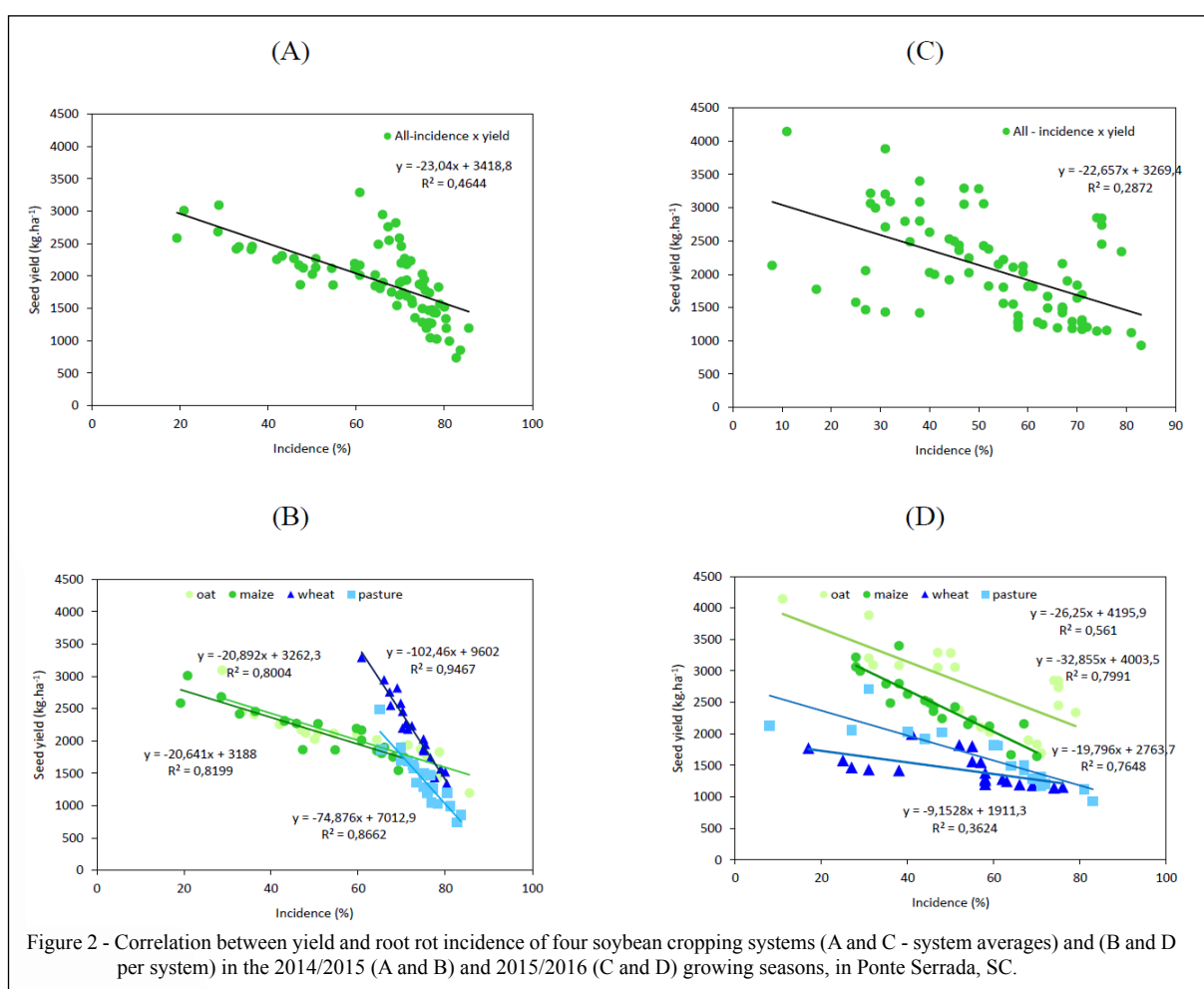
<sup>1</sup>Means followed by the same upper case letter in the column (system comparison) do not differ according to Duncan's test, at 5% probability. <sup>2</sup>Means preceded by the same lower letter on the line (growing season comparison) do not differ according to the F-test at 5% probability. <sup>3</sup>Differ according to the F-test at 5% probability.

increase in RR incidence in the first and second seasons, respectively (Figure 2A and C). Individual analysis of cropping system demonstrated a decrease in SY of 20.9; 20.6; 102.9 and 74.9 kg ha<sup>-1</sup> per 1% increase in RR for soybean+oat, soybean+maize, soybean+wheat and soybean+pasture systems, respectively (Figure 2B). In the 2015/2016 season, SY fell by 26.3, 32.9, 9.2 and 19.8 kg ha<sup>-1</sup> per 1% increase in RR, for soybean+oat, soybean+maize, soybean+wheat and soybean+pasture systems, respectively (Figure 2D). A comparison of all the systems with RR showed that yield declined with the increase in diseases, regardless of season, cropping system and the presence of dead patches in soybean crops (Figure 2). The soybean+oat and soybean+maize cropping systems were consistently more productive in healthy than unhealthy plants, with differences of more than 158 and 286 kg ha<sup>-1</sup> in the first season and 426 and 416 kg ha<sup>-1</sup> in the second season, respectively (Table 1). Results reported by REIS et al. (2014) demonstrated

that soybean grown after maize was more productive than a soybean monoculture grown after winter grasses. These authors also reported more *Macrophomina* than *Fusarium* in soybean plant roots. JULIO et al. (2016) obtained higher soybean yield in a millet-soybean succession system than fallow-soybean, maintaining healthy plants to harvesting maturity stage.

## CONCLUSION

In the 2014/2015 and 2015/2016 growing seasons, grey rot predominated in relation to sudden death syndrome. Incidence of RR, regardless of crop, early or late RR symptoms and cropping system was more than 50%, resulting in losses of 22 kg ha<sup>-1</sup> of seeds per 1% increase in RR, or between 1.5 and 7.1 bags ha<sup>-1</sup> of soybean seeds. The soybean+oat and soybean+maize cropping systems were consistently more productive than their soybean+wheat and soybean+pasture counterparts.



## ACKNOWLEDGEMENTS

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq/Universal 460983/2014-8); Coordenação de Aperfeiçoamento de Pessoal de Nível Superior/Programa de Apoio à Pós-graduação (CAPES/PROAP) and Fundação de Amparo a Pesquisa e Inovação do Estado de Santa Catarina (FAPESC/PAP/UDESC) research funding agencies for financial support. To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) Research Productivity Scholarship, Brazil, for the Souza, C.A. and to Casa, R.C. and, FAPESC/Promop for the study grants awarded for Maier, M.

## CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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