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Soil management, seed treatment and soil compaction on the sowing furrows affect grain yields of upland rice genotypes

Veneraldo Pinheiro, Luís Fernando Stone, Adriano Stephan Nascente*

Brazilian Agricultural Research Corporation (EMBRAPA), Rice and Beans Research Center, PO Box 179, 75375-000, Santo Antônio de Goiás, State of Goiás, Brazil

***Corresponding author: adriano.nascente@embrapa.br**

Abstract

The water availability for flood irrigated rice (*Oryza sativa* L.) is decreasing worldwide. Therefore, developing technologies to allow growing rice in aerobic condition, such as a no-tillage system (NTS) can contribute to produce upland rice grains without yield losses and also in saving more water. The objective of this study was to determine the effect of soil management, seed treatment and compaction on the sowing furrow on grain yield of upland rice genotypes. We made two trials, one in an NTS and another using conventional tillage, CT (one plowing and two diskings). The field experiments were performed in the Central Region of Brazil in Cerrado soils. For each trial, the experimental design was a randomized block design in a factorial scheme, with three replications. The treatments consisted of a combination of 10 genotypes with 2 compaction pressures on the sowing furrow (25 kPa and 126kPa) and 2 types of seed treatment (with and without pesticide). Under CT, the seed treatment did not contribute to increase upland rice grain yields. However, under NTS the grain yield of some genotypes [BRS Esmeralda (from 723 to 1,766 kg ha^{-1}), BRS Pepita (from 930 to 1,874 kg ha^{-1}), AB072044 (from 523 to 1,579 kg ha^{-1}), and AB072085 (from 632 to 1,636 kg ha^{-1}) at 25 kPA soil compaction pressure, and Sertaneja (from 994 to 2,167 kg ha^{-1}), BRS Pepita (from 1,161 to 2,100 kg ha^{-1}), and AB072085 (from 958 to 2,213 kg ha^{-1}), at 126 kPA soil compaction pressure] increased with the use of this practice. At CT the higher soil compaction pressure on the sowing furrow (from 25 kPa to 126 kPa) increased rice grain yield only when it was used seed treatment and the genotypes Serra Dourada (from 1,239 to 2,178 kg ha^{-1}), Sertaneja (from 1,510 to 2,379 kg ha^{-1}), and Cambará (from 1,877 to 2,831 kg ha^{-1}). On the other hand, under NTS, increasing soil compaction pressure on the sowing furrow allowed for an increased rice grain yield of Serra Dourada (from 1,553 to 2,347 kg ha^{-1}), Esmeralda (from 723 to 1,643 kg ha^{-1}), AB072044 (from 523 to 2,040 kg ha^{-1}), and Cambará (from 1,243 to 2,032 kg ha^{-1}) without seed treatment and Sertaneja (from 1,385 to 2,167 kg ha^{-1}) and AB072044 (from 1,579 to 2,356 kg ha^{-1}) with seed treatment. In CT the most productive genotypes were AB062008 (2,714 kg ha^{-1}) and BRSMG Caravera (2,479 kg ha^{-1}), while at NTS were the genotypes: BRSGO Serra Dourada (2,118 kg ha^{-1}), AB072047 (1,888 kg ha^{-1}), AB062008 (1,823 kg ha^{-1}), BRSMG Caravera (1,737 kg ha^{-1}), Cambará (1,716 kg ha^{-1}), AB072044 (1,625 kg ha^{-1}), BRS Esmeralda (1,604 kg ha^{-1}), and BRS Pepita (1,516 kg ha^{-1}).

Keywords: Termite; pesticide; no-tillage system; conventional tillage.
Abbreviations: NTS_no-tillage system; CT_conventional tillage; CSF_compaction on the sowing furrow.

Introduction

Rice is included in the diet of half of the world's population, this cereal is mostly grown under irrigation. However, available water resources have been reduced because of the competing demands of industry and population, and consequently, alternatives are sought that allow for a greater efficiency of water use (Prasad, 2011). Some alternatives include growing rice under aerobic conditions, such as in a no-tillage system (NTS) (Nascente et al., 2013a). The NTS, due to the benefits provided to the environment, such as greater conservation of water, increasing soil fertility and organic matter content and increased protection of the soil against erosion, had significant global growth, being used in almost 117 million ha distributed throughout Latin America (58 million ha), the US, Canada (40 million ha) and Australia (17 million hectares) (FAOSTAT, 2014). In Brazilian agriculture, NTS is used in 25 million ha of the cultivated area, of which the total is about 50 million ha (Nascente and Crusciol, 2012). However, upland rice crops are not having good development under NTS (Olofintoye and Mabbayad, 1980; Kluthcouski et al., 2000; Crusciol et al, 2010; Nascente et al, 2011; Nascente et al., 2013b). Therefore, it is important to develop technologies to reach high rice grain yields under an NTS, aiming for sustainable agriculture, increased food production and more water being saved (Farooq et al., 2009).
The 0-0.05 m soil layer under an NTS usually shows high porosity, because of the action of the seeder discs, higher concentration of roots and organic matter, greater biological activity and more cycles of soil wetting and drying (Silva, 2003), which can hinder the contact of rice seed with soil and can reduce plant emergence. The compaction on the sowing furrow (CSF) improves the contact of the soil with the seeds, allowing them to absorb the water earlier and germinate faster (Silva, 2006). The use of this practice provided increases of 40% in plant stand and 15% in the lowland rice yield (Soares and Carrão, 1993) and 17% in upland rice grain yield under NTS (Portugal et al., 2013). Another problem that can cause decrease in rice grain yield under NTS is termite (*Proconiter mes* spp and *Syntermes molestus*) damage. These

insects occur in most rice fields established in Cerrado soils, causing significant losses in crop grain yield and are the main reason to use insecticide in treating seeds for sowing (Ferreira et al., 2007). The use of CSF also helps to minimize the damage caused by these termites. Barrigossi et al. (2011) observed that the termites attack on upland rice grown under NTS was lower with CSF and reported that the benefit of this practice is reinforced when combined with seed treatment using insecticides.

According to Radford and Allsopp (1987), soil compaction with a press wheel consistently and markedly improved the establishment of sorghum and sunflower on insect-infested soils in southern Queensland. They attributed these responses to an improvement in the soil-water supply and a reduction in the lethal damage to seeds and seedlings by a wide range of insect species. Compaction over the row may squash large insect pests near the seed, killing or injuring them; it may restrict the movement of insects through the soil; it may improve soil water supply enabling seedlings to escape pest damage by faster germination and growth; or, by reducing soil porosity, it may reduce carbon dioxide diffusion from the seed/seedling. They also related that the use of insecticides in addition to press wheels enhanced establishment in some situations.

Upland rice genotypes have a different response for grain yield according to soil tillage (Moura Neto et al., 2002; Guimarães et al., 2006; Reis et al., 2007; Nascente et al., 2011, 2013b). Therefore, it is fundamental to identify genotypes more adapted for each system and we can infer that the choice of cultivar is a determinant factor for the success of growing rice using an NTS.

We have three hypotheses: 1. Upland rice genotypes have different behavior under NTS and CT; 2. Increasing compaction on the sowing furrow will provide better development of rice plants; and 3. Use of seed treatment against termites provides for better plant development. The objective of this study was to determine the effect of soil management, seed treatment and compaction on the sowing furrow on the grain yield of upland rice genotypes.

Results and Discussion

In both experiments, there was a significant effect of triple interaction: genotype, compaction pressure, and seed treatment (Table 1).

Conventional tillage

Under conventional tillage, the use of seed treatment did not significantly affect genotypes' grain yields (Table 1). The increased soil compaction pressure on the sowing furrow, in turn, has increased the grain yield of the genotypes BRSGO Serra Dourada (from 1,239 to 2,178 kg ha^{-1}), Sertaneja (from 1,510 to 2,379 kg ha^{-1}) and Cambará (from 1,877 to 2,831 kg ha^{-1}), when the seeds were treated (Table 2). The effects of using or omitting the use of depth-gauges and press wheels on no-till corn, soybean, and wheat sowing with an offset double-disc seed opener were investigated by Chen et al. (2004). These authors reported that removing the press wheel reduced the speed of emergence and final stand. Based on our results, we can infer that the seeds of these genotypes (BRSGO Serra Dourada, Sertaneja and Cambará) are more sensitive to a higher porosity of the soil that is provided by soil tillage, and that soil compaction only on the soil furrow performed by the "V" wheel of the seeding machine was not enough to improve the adherence of soil to seed. These genotypes, in order to increase productivity must use higher soil compaction on the sowing furrow. Silva (2006) reported that the soil compaction on the sowing furrows provides for better contact of the soil with the seed, resulting in earlier water absorption and faster germination. On the other hand, the other genotypes can be sown without further compaction on the sowing furrows, since their productivity will not be affected.

No-tillage system

Under no-tillage, the use of seed treatment increased the grain yield of the genotypes BRS Esmeralda (from 723 to 1,766 kg ha^{-1}) and AB072044 (from 523 to 1,579 kg ha^{-1}), when the soil compaction pressure on the sowing furrow of 25 kPa was used, and of Sertaneja at 126 kPa soilcompaction pressure (from 994 to 2,167 kg ha^{-1}). For the genotypes BRSGO Pepita and AB072085 the increase in grain yield occurs in both compaction pressures, respectively from 930 to 1,874 kg ha^{-1} at 25 kPa and from 1161 to 2,100 kg ha^{-1} at 126 kPa, and from compaction pressures of 632 to 1,636 kg ha^{-1} at 25 kPa and 958 to 2,213 kg ha^{-1} at 126 kPa (Table 3).
Based on the results it can be inferred that the practice of seed treatment was effective in controlling main rice pests, resulting in increased productivity in some genotypes, and must be used. Termite damage is compounded under no-tillage because it provides straw accumulation on the soil surface, increasing the availability of food for termites and can cause a total loss of production (Barbosa et al., 2009). In addition, in this system there is no reduction in the population of these insects by exposure, crushing and the destruction of galleries, as in conventional tillage. Therefore, it is likely that the genotypes BRS Esmeralda, AB072044, Sertaneja, BRSGO Pepita and AB072085 had less termite attacks due the insecticides used in the seeds, and the compaction provided better control of this insect, which resulted in a higher grain yield. Radford and Allsopp (1987) related that the use of insecticides in addition to press wheels enhanced plant establishment. The other genotypes probably had no termite attacks and did not have an effect on the grain yield. According to Barrigossi et al. (2011) termite have a preference for some rice genotypes. They suggested that termites prefer genotypes with soft root systems that reduce the resistance to be attacked by these termites.

On the other hand, in the absence of seed treatment, the greater soil compaction pressure on the sowing furrow increased the grain yield of the genotypes BRSGO Serra Dourada (from 1,553 to 2,347 kg ha^{-1}), BRS Esmeralda (723 to 1,643 kg ha^{-1}), AB072044 (523 to 2,040 kg ha^{-1}), and Cambará (from 1,243 to 2,032 kg ha^{-1}) (Table 3). With the use of seed treatment, 126 kPa soil compaction pressures on the sowing furrow provided higher grain yield of the genotypes Sertaneja (from 1,385 to 2,167 kg ha^{-1}) and AB072044 (from 1.579 to 2.356 kg ha^{-1}). Thus, it can be seen that even without pesticide, the soil compaction pressure on the sowing furrow alone is effective to provide significant increases in the productivity of some genotypes. This information is interesting because if the producer does not have funds for the purchase of the pesticide, an alternative would be for compaction on the sowing furrow. Radford and Allsopp (1987) reported that soil compaction with a press wheel provided a reduction in the lethal damage to seeds and seedlings by a wide range of insect species.

Cultivars at conventional tillage

The most productive genotype under conventional tillage was AB062008 (2,714 kg ha^{-1}) and it did not differ from BRSMG

Table 1. Summary of variance analysis for upland rice grain yield.

Source of variation	FD[+]	Medium square	
		Conventional tillage	No-tillage system
Block	2	123,022^{ns}	22,814^{ns}
Seed treatment (ST)	1	790,239**	10,720,945**
Compaction Pressure (CP)	1	4,229,257**	8,525,868**
Genotype (G)	9	1,310,247**	663,844**
Interaction ST x CP	1	101,268^{ns}	11,682^{ns}
Interaction ST x G	9	203,995**	368,753**
Interaction CP x G	9	202,567**	239,437**
Interaction ST x CP x G	9	141,536*	146,914**
Residue		62,402	53,740
CV (%)		12.0	13.8

[+]Freedon degree. ns no significance. **,* significance at 0.05 and 0.01, respectively.

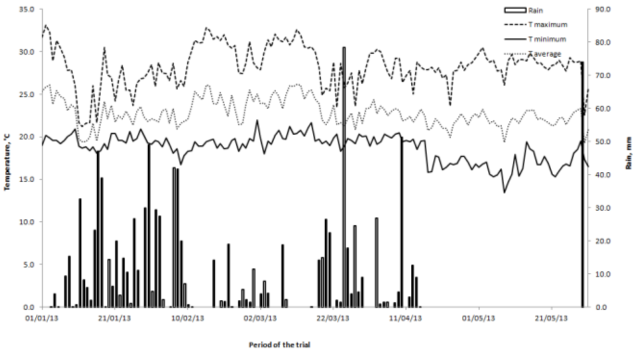

Fig 1. Maximum, minimum and average temperatures (T) and rainfall in the experimental field of Capivara Farm (Santo Antônio de Goiás), during the experimental period in the growing season 2013.

Table 2. Upland rice grain yield at conventional tillage, as a function of seed treatment and compaction pressure on the sowing furrow. Santo Antônio de Goiás, GO, Brazil, crop season 2013.

Genotype	Seed treatment			
	Without		With	
	Compaction pressure on the sowing furrow			
	25 kPa	126 kPa	25 kPa	126 kPa
BRSGO Serra Dourada	1,750aA[+]	1,877aA	1,239bA	2,178aA
BRS Esmeralda	1,790aA	2,301aA	1,780aA	2,314aA
BRSMG Caravera	2,198aA	2,828aA	2,418aA	2,473aA
Sertaneja	1,437aA	2,162aA	1,510bA	2,379aA
BRS Pepita	1,608aA	1,769aA	1,835aA	2,369aA
AB072044	1,949aA	2,342aA	1,889aA	1,965aA
AB072047	1,403aA	1,652aA	1,556aA	1,839aA
AB072085	1,844aA	1,877aA	2,577aA	2,322aA
AB062008	2,520aA	2,524aA	2,733aA	3,081aA
Cambará	1,875aA	2,214aA	1,877bA	2,831aA
Average	1,837bA	2,155aB	1,941bA	2,375aA

[+] Means followed by the same capital letter in the line does not differ at 5% probability by Tukey's test in seed treatment compared within the compaction on the sowing furrow and followed by the same lower case letter in compaction on the sowing furrow within seed treatment levels.

Table 3. Upland rice grain yield at no-tillage system, as a function of seed treatment and compaction pressure on the sowing furrow. Santo Antônio de Goiás, GO, Brazil, crop season 2013.

Genotype	Seed treatment			
	Without		With	
	Compaction pressure on the sowing furrow			
	25 kPa	126 kPa	25 kPa	126 kPa
BRSGO Serra Dourada	1,553bA	2,347aA	1,985aA	2,587aA
BRS Esmeralda	723bB	1,643aA	1,766aA	2,286aA
BRSMG Caravera	1,452aA	1,688aA	1,746aA	2,063aA
Sertaneja	909aA	994aB	1,385bA	2,167aA
BRS Pepita	930aB	1,161aB	1,874aA	2,100aA
AB072044	523bB	2,040aA	1,579bA	2,356aA
AB072047	1,842aA	1,839aA	1,711aA	2,160aA
AB072085	632aB	958aB	1,636aA	2,213aA
AB062008	1,193aA	1,824aA	1,829aA	2,446aA
Cambará	1,243bA	2,032aA	1,661aA	1,928aA
Average	1,100bB	1,653aB	1,717bA	2,231aA

[+] Means followed by the same capital letter in the line does not differ at 5% probability by Tukey's test in seed treatment compared within the compaction on the sowing furrow and followed by the same lower case letter in compaction on the sowing furrow within seed treatment levels.

Table 4. Grain yield of upland rice genotypes at conventional tillage and no-tillage system.

Genotype	Grain yield (kg ha^{-1})	
	Conventional tillage	No-tillage system
BRSGO Serra Dourada	1,761cd^{+}	2,118a
BRS Esmeralda	2,047bcd	1,604ab
BRSMG Caravera	2,479ab	1,737ab
Sertaneja	1,872cd	1,364b
BRS Pepita	1,895cd	1,516ab
AB072044	2,036bcd	1,625ab
AB072047	1,612d	1,888ab
AB072085	2,155bc	1,360b
AB062008	2,714a	1,823ab
Cambará	2,199bc	1,716ab

$^{+}$Means followed by the same letter in column does not differ at 5% probability by Tukey's test.

Caravera genotype (2,479 kg ha^{-1}), but it differed from all other genotypes (Table 4). Nascente et al. (2011) found that among eight genotypes evaluated, Carajás, Caiapó, BRS Pepita, BRS Monarca, BRSMG Curinga and BRS Bonança show similar grain yields. Nascente et al. (2013b) found that the genotypes BRS Sertaneja, BRS Primavera, BRSMG Curinga, Caiapó and BRS Bonança also had statistically similar productivity. Based on our results, we can infer that between the materials evaluated, AB062008 and BRSMG Caravera genotypes are the most suitable to be grown by farmers under conventional tillage.

Cultivars at no-tillage system

The most productive genotype was BRSGO Serra Dourada (2,118 kg ha^{-1}), which was statistically different from the Sertaneja (1,364 kg ha^{-1}) and AB072085 (1,360 kg ha^{-1}) genotypes (Table 4). Nascente et al. (2011) reported that the genotypes which provided higher grain yields under NTS were Caiapó, Carajás, BRS Pepita, BRS Monarca, BRSMG Curinga, and BRS Bonança. In the work of Nascente et al. (2013b), the most productive genotypes were BRS Primavera and BRSMG Curinga. The genotypes BRSGO Serra Dourada, AB072047, AB062008, BRSMG Caravera, Cambará, AB072044, BRS Esmeralda, and BRS Pepita did not differ and can be recommended for rice cultivation in NTSs.

Final consideration

Based on the results of two experiments it can be concluded that the genotypes exhibit different behaviors depending on the soil tillage. These results corroborate the works of Moura Neto et al. (2002), Guimarães et al. (2006), Nascente et al. (2011) and Nascente et al. (2013b), which showed that the performance of rice genotypes varies with conventional tillage and no-tillage. It is necessary that the producers observe these results when they grow rice in order to improve the chances of increased productivity. Seed treatment with pesticide and soil compaction on the sowing furrow were effective practices to provide significant increases in grain yield of some tested genotypes and, therefore, should be observed in the crop implementation. Once the triple interaction occurs between treatments, the most appropriate management to provide the highest grain yields (soil compaction pressure and seed treatment) should be selected according to the chosen genotype.

Materials and Methods

Site description

The experiments were located in the Capivara Farm, which is located in Santo Antônio de Goiás, GO, Brazil, at 16º28'00" S and 49º17'00" W, and at an altitude of 823 m. The climate is tropical savanna, considered Aw according to the Köppen classification (Köppen and Geiger, 1936). There are two distinct seasons, usually dry from May to September (fall/winter) and rainy from October to April (spring/summer). During the experiment, the temperature and amount of rainfall data were recorded (Fig 1).

The soil in both locations was classified as a sandy clay loam (kaolinitic, thermic Typic Haplorthox). The experimental areas have been under a degraded pasture of *Brachiaria brizantha* for 24 years. The values of the soil texture in the 0-0.20 m layer were 311 g kg^{-1} of sand, 120 g kg^{-1} silt, and 569 g kg^{-1} clay. Before the application of treatments, the chemical characteristics of the soil were determined according to the methods described by Claessen (1997). The results were: pH (H_2O) = 5.6; Ca^{2+} = 9.0 mmol$_c$ dm^{-3}; Mg^{2+} = 6.0 mmol$_c$ dm^{-3}; Al^{3+} = 1.0 mmol$_c$ dm^{-3}; H^+ + Al^{3+} = 49.0 mmol$_c$ dm^{-3}; P = 0.8 mg dm^{-3}; K^+ = 108.0 mg dm^{-3}; Cu^{2+} = 4.1 mg dm^{-3}; Zn^{2+} = 1.5 mg dm^{-3}; Fe^{3+} = 151.0 mg dm^{-3}, and Mn^{2+} = 58.0 mg dm^{-3}.

Experimental design and treatments

Two trials were performed, one under a no-tillage system and the other using conventional tillage (one plowing and two diskings). Experiments were arranged in a randomized complete block design in a factorial scheme 10 x 2 x 2, with three replications. The treatments consisted of the combination of 10 genotypes, with two compaction pressures on the sowing furrow and two types of seed treatment.The plots had the dimensions of 1.84 m (4 rows of rice) wide x 20 m long. The usable area of the plot was composed of two central rows of rice, disregarding 0.50 m on each side.

The seed treatments were with and without the application of Fipronil + Pyraclostrobin + ThiophanateMethyl (62.5 + 0.625 + 50.625 ml a.i. /100 kg of seed) (Standak® Top – Basf). The compaction pressure were 25 kPa was provided by the original "V" press wheels of the seed drill and 126 kPa provided by the mass of 635.0 kg on the front axle of an MF 5275 4 x 2 tractor with 7.50-16 bald directional vehicular tires (no "treads", larger contact area) with no additional ballast. The rear tire contact area had been increased and its mass was removed to the maximum to decrease its influence in the sowing furrow. The genotypes studied were BRSGO Serra Dourada, BRS Esmeralda, BRSMG Caravera, Sertaneja, BRS Pepita, AB072044, AB072047, AB072085, AB062008, and Cambará.

Crop management

The sowing was performed mechanically, using 50 kg ha^{-1} of rice seeds. The seed was sown on January 7th, 2013. Rice plant emergency occurred five days after sowing. The row spacing used was 0.46 m, with 90 viable seeds per meter. The sowing fertilization was made based on the soil analysis, following the recommendations of Sousa and Lobato (2003), in the amounts of 13 kg ha^{-1} of N as urea, 80 kg ha^{-1} of P_2O_5 as triple superphosphate, 40 kg ha^{-1} of K_2O as potassium chloride. Topdressing fertilization was performed on January 23rd, 2013 using 55 kg ha^{-1} of N as urea. Cultural practices were performed according to standard recommendations for rice crops to keep the area free from weeds, diseases and insects.

Rice harvesting

Rice harvesting was made after physiological maturity (May, 3rd, 2013), by hand in the usable area in each plot. Plots were evaluated regarding grain yield, which was determined by weighing the harvested grain of each plot, corrected to 13% of water content and converted to kg ha^{-1}.

Statistical analysis

For statistical analysis, the SAS Statistical Software, SAS Institute, Cary, NC, USA (SAS, 1999) was used. Data was subjected to an analysis of variance and, when the F test proved significant, compared by Tukey's test at $p \leq 0.05$.

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Conclusions

Rice genotypes showed different behavior according to soil management. Under conventional tillage, seed treatment did not contribute to increase the upland rice grain yield. However, under no-tillage, the grain yield of some genotypes [BRS Esmeralda (from 723 to 1,766 kg ha^{-1}), BRS Pepita (from 930 to 1,874 kg ha^{-1}), AB072044 (from 523 to 1,579 kg ha^{-1}), and AB072085 (from 632 to 1,636 kg ha^{-1}) at 25 kPA soil compaction pressure, and Sertaneja (from 994 to 2,167 kg ha^{-1}), BRS Pepita (from 1,161 to 2,100 kg ha^{-1}), and AB072085 (from 958 to 2,213 kg ha^{-1}), at 126 kPA soil compaction pressure] increased with the use of this practice. This probably occurs due to the termite damage being compounded under no-tillage system. Regarding the higher soil compaction pressure on the sowing furrow (from 25 kPa to 126 kPa), in conventional tillage, there was an increase of upland rice productivity only when seed treatment and the genotypes Serra Dourada (from 1,239 to 2,178 kg ha^{-1}), Sertaneja (from 1,510 to 2,379 kg ha^{-1}), and Cambará (from 1,877 to 2,831 kg ha^{-1}) were used. However, under NTS, increasing soil compaction pressure on the sowing furrow allowed for an increasing rice grain yield of Serra Dourada (from 1,553 to 2,347 kg ha^{-1}), Esmeralda (from 723 to 1,643 kg ha^{-1}), AB072044 (from 523 to 2,040 kg ha^{-1}), and Cambará (from 1,243 to 2,032 kg ha^{-1}) without seed treatment and Sertaneja (from 1,385 to 2,167 kg ha^{-1}) and AB072044 (from 1,579 to 2,356 kg ha^{-1}) with seed treatment. These responses are likely related to an improvement in the soil-water supply and a reduction in the lethal damage to seeds and seedlings by the termites. Using CT the most productive genotypes were AB062008 (2,714 kg ha^{-1}) and BRSMG Caravera (2,479 kg ha^{-1}), while under NTS the genotypes were: BRSGO Serra Dourada (2,118 kg ha^{-1}), AB072047 (1,888 kg ha^{-1}), AB062008 (1,823 kg ha^{-1}), BRSMG Caravera (1,737 kg ha^{-1}), Cambará (1,716 kg ha^{-1}), AB072044 (1,625 kg ha^{-1}), BRS Esmeralda (1,604 kg ha^{-1}), and BRS Pepita (1,516 kg ha^{-1}).

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