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Soybean sowing under low water availability conditions: impacts of seed treatment and soil management

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ABSTRACT: The aim of this work was to evaluate the impact of soybean sowing in soil with low water availability, under two management systems, using seeds with and without chemical treatment, on the physiological quality of seeds and seedling emergence. For this, two experiments were set up, one under no-tillage system (NTS) and the other under conventional tillage system (CTS), in a randomized block design, both in a 2x6 factorial scheme, with two seed treatment conditions (with and without) and six periods of seed permanence in the soil (0, 24, 48, 72, 96 and 120 h), with four replications. Germination, vigor, percentage of abnormal seedlings and percentage of dead seeds were evaluated. Seed treatment made it possible to maintain germination at acceptable levels for up to five days of permanence of the seeds in the soil, even in CTS. Sowing in soils with low water availability can lead to reductions of 0.2 and 0.5 percentage points per hour of exposure to dry soil in germination and vigor of soybean seeds, respectively.

Index terms: no-tillage, plant emergence, seedling protection, seed vigor, soil moisture.

RESUMO: O objetivo deste trabalho foi avaliar o impacto da semeadura da soja em solo com baixa disponibilidade hídrica, sob dois sistemas de manejo, utilizando sementes com e sem tratamento químico; sobre a qualidade fisiológica das sementes e emergência de plântulas. Para isso, instalou-se dois experimentos, um em sistema de plantio direto (NTS) e outro sob sistema de plantio convencional (CTS), em delineamento de blocos casualizados, ambos em esquema fatorial 2x6, com duas condições de tratamento de sementes (com e sem) e seis períodos de permanência das sementes no solo (0, 24, 48, 72, 96 e 120 h), com quatro repetições. Foram avaliadas a germinação, o vigor, o percentual de plântulas anormais e o percentual de sementes mortas. O tratamento de sementes possibilitou a manutenção da germinação em níveis aceitáveis até cinco dias de permanência das sementes no solo, mesmo em CTS. A semeadura em solos com baixa disponibilidade hídrica pode acarretar reduções de 0,2 e 0,5 ponto percentual por hora de exposição ao solo seco na germinação e no vigor das sementes de soja, respectivamente.

Termos para indexação: plantio direto, emergência de plantas, proteção de plântulas, vigor de sementes, umidade do solo.

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INTRODUCTION

The high yields achieved by the national soybean cultivation demand proper establishment of plantations as a fundamental principle. This process is dependent on several factors, starting with the use of high-vigor seeds, sowing in the indicated periods, and ideal conditions of temperature and humidity for germination and emergence, resulting in the desired plant population according to the chosen genotype, as a function of the adequacy of plant architecture (Bagateli et al., 2020).

However, in the establishment of plantations, climate and soil conditions are not always ideal for the sowing operation, with situations in which there may be high or low soil moisture, associated or not with high or low temperature in the initial period of germination and emergence of soybean crop. In this scenario, sowing under conditions of low water availability in the soil, popularly referred to as sowing or planting in dry soil, has become a frequent practice in agricultural properties. The increased adoption of this practice is associated with the increase in the cultivated area and aims to ensure sowing within the appropriate window for the genotype, optimizing the use of machines, in addition to maintaining the second-season sowing forecast within the indicated window, reducing the probability of possible climatic problems such as excessive rain at harvest and more severe infections of Asian rust, very common in later sowing (Ferrari et al., 2015).

As highlighted by Rezende et al. (2003), to obtain the appropriate stand and avoid resowing operations, sowing in dry soil should be carried out based on well-defined criteria, such as forecast of rainfall within a short period of time, as this will condition seed germination and seedling emergence. In this context, Peske and Delouche (1985) establish that after sowing under low soil moisture conditions, the rain must occur within a period of five to ten days, otherwise the seed will deteriorate in the soil at such a level that it may become unable to germinate and emerge, even when the ideal conditions are satisfied.

Water availability to soybean crop is very important in the germination-emergence and flowering-grain filling periods (Farias et al., 2007). Considering the sowing operation, both excess and lack of water are harmful to crop establishment and to obtaining a good uniformity in plant population, but water excess is more limiting than water deficit. The same authors also point out that soybean seed needs to absorb at least 50% of its weight in water to ensure good germination and, for this, the water content in the soil should not exceed 85% of the maximum available total or be less than 50%.

Besides water availability, temperature is an important environmental factor to be faced by seeds stored in the soil and, consequently, the type of soil management where the crop will be planted, known as no-tillage system (NTS) or conventional tillage system (CTS), has direct influence on both soil temperature and maintenance of soil moisture. This is due to the greater or lesser exposure of the soil surface to solar radiation and, consequently, the increase of temperature in the surface layer associated with greater evaporation of moisture (Rosseto et al., 2017).

Martorano et al. (2009) stated that the maximum temperature under CTS is an indicator of greater daytime thermal effects of soil heat flux, while the attenuation observed in the maximum temperatures under NTS is associated with the effects of straw and with the higher soil water contents in the surface layers. Furthermore, these authors concluded that the soil drying time was longer under NTS, indicating less negative matric potential, lower maximum temperature and lower thermal amplitude compared to the CTS.

In addition to the factors mentioned, the period of permanence of seeds in the soil, where they await the appropriate conditions for germination, exposes them to the attack of pathogenic fungi with high-risk potential of reduction in seed viability (Peske and Delouche, 1985; Farias et al., 2007). In the absence of ideal conditions, soybean germination and emergence occur more slowly, providing fungi found in the soil and in the seed itself with a greater opportunity for attack, so they can cause seed deterioration or even seedling death. In order to minimize such deleterious effects, it is recommended to treat seeds with fungicides (Pereira et al., 2017).

Given this potentially unfavorable scenario, understanding the relationships of tillage systems and sowing conditions is extremely important in the attempt to minimize the negative effects on planting and avoid resowing, to ensure the proper establishment of soybean crop. In this context, the objective of this study was to evaluate the effect of soybean sowing on the physiological quality of seeds stored in soil and on seedling emergence, when sown in soils with different types of management and with low water availability, using seeds with and without chemical treatment.

MATERIAL AND METHODS

The study was carried out in Los Cedrales, State of Alto Paraná - Paraguay (25°39’3.04” S and 54°42’50.37” W and 250 m altitude). The soil of the site has clayey texture, containing 72.8, 17.1 and 10.1% of clay, silt and sand, respectively, being classified as Oxisol according to the American classification (Soil Taxonomy) adopted in Paraguay. The current Brazilian soil classification includes it in the *Latossolo Vermelho Eutroférrico* class (EMBRAPA, 2013).

Two experiments were conducted, the first in soil with no-tillage system (NTS) and the second under a conventional tillage system (CTS). In the experiment with NTS, sowing was performed on black oat (*Avena strigosa*; cv. Neblina) straw previously dried 40 days before installation. Conversely, in the experiment with CTS, sowing was carried out in the total absence of vegetation cover. In the latter, after the harvest of the summer soybean crop, the site received successive harrowing operations, to leave the soil exposed. In each experiment, the design used was complete randomized blocks, arranged in a 2 x 6 factorial scheme, composed of two types of seed treatment (with and without chemical treatment) and six periods of permanence of seeds in the soil (0; 24; 48; 72; 96 and 120 h) after sowing, with four replications, in a total of 48 plots per experiment.

Both experiments were conducted using seeds of the genotype 63i64 RSF IPRO, standardized with 6.0 mm diameter; 2-kg samples referring to each experimental plot were collected from the lot and then, for the condition in which the seeds received chemical treatment (With treatment - WiT), these were treated with the fungicides thiabendazole (150 $g.L^{-1}$), metalaxyl-M (20 $g.L^{-1}$) and fludioxonil (20 $g.L^{-1}$), at the dose of 100 mL.100 kg^{-1} seeds of the commercial product Maxim Advanced®. For this operation, a batch machine was used to simulate the industrial treatment, ensuring the necessary coating of the seeds with the product. No product was applied to the seeds in the untreated condition (Without treatment - WoT). Then, each sample was subjected to the determination of moisture level, germination, and vigor (considered as permanence period of 0 h); subsequently, the rest of the seeds were sown in the field.

Sowing was performed on September 21, 2020, with no fertilizers, using a plot seeder, Semeato brand, PH model, with three rows spaced 0.45 m apart and a mechanical seed distribution system with a metering box, using a horizontal disc with 8.0-mm-diameter circular hole. The furrower was composed of dual mismatched discs with 15-inch diameter, which create in a V-shaped furrow, coupled to a flat band-type closer with a rubber wheel, which kept the compactor on the sowing furrow. The travel speed was 3 $km.hour^{-1}$, with placement depth of 0.05 m and distribution of 25 $seeds.m^{-1}$. Each experimental unit consisted of nine sowing rows with 15 m in length.

After sowing and within each permanence period established (24, 48, 72, 96 and 120 h), 1,000 seeds per plot were manually collected directly from the sowing furrow in four rows along 12 m in length. Then, the samples were taken to the laboratory and subjected to moisture content determination and to physiological quality tests. After the end of the collection periods within the pre-established times, the remainder of the plot (five rows) received artificial irrigation via sprinklers, applying a 24 mm water depth.

The variables analyzed were germination percentage, abnormal seedlings and dead seeds according to methodology described by the Rules for Seed Testing (Brasil, 2009), using sand substrate at 25 °C, in four replications of 50 seeds. Vigor was evaluated by the methodology of seedling classification in the germination test, as described by Krzyzanowski et al. (2020). The percentage of plant emergence in the field, where irrigation was applied, was determined by counting the emerged seedlings, considering the distribution of the initial amount of 25 $seeds.m^{-1}$. This measurement was performed 120 h after irrigation.

In addition to the response variables, seed moisture content was monitored by the oven method at 105 °C for 24 h (Brasil, 2009) within each permanence period evaluated (Figure 1b). The monitoring of soil moisture levels at depths from 0.00 to 0.10 m and from 0.11 to 0.20 m was performed within each plot, using direct reading device of Delta T Devices, HH2 model, coupled with the moisture sensor ML3 Thetaprobe, properly calibrated (Figure 1a). The daily readings were performed at the same time and represent the average position of the device at five points within the usable area of the plot, at each established depth.

On the other hand, the environment and soil temperatures were monitored by dataloggers from the Testo brand, 174H model (Figure 2a). For the measurement of soil temperature, a probe was inserted into the soil up to the seed placement depth (0.05 m) and kept for the entire period of study, in both sowing systems (Figure 2b).

The results were checked for normality and homoscedasticity of variances and then subjected to analysis of variance by the Fischer test. The effects of seed permanence periods were evaluated by polynomial regressions. The data were analyzed in the statistical program Rbio (Bhering, 2017), at 5% probability level in all analyses.

RESULTS AND DISCUSSION

The analysis of variance revealed (Table 1) interactions between the experimental factors in both experiments (NTS and CTS), for all variables evaluated. As plant emergence was evaluated in only one period, it was not presented in the summary of the analysis of variance.

In the NTS experiment, linear reductions of approximately 5 and 2 (percentage points) p.p.day^{-1} were observed in the germination of seeds WoT and WiT, respectively (Figure 3a), with coefficients of determination (R^2) of 0.97 and 0.79, indicating that most of the variations can be explained by the fitted equations. In the CTS, for the same period, the estimates of linear reductions were higher, reaching 13 and 3 p.p.day^{-1} for seeds WoT (R^2: 0.90) and WiT (R^2: 0.97), respectively (Figure 4a). In a similar study, the condition of water stress after sowing also influenced the germination of soybean seeds, causing a linear reduction; for each day of water deficit after sowing, there was a reduction of 4.14% in the germination of soybean seed, regardless of the cultivar, reaching 0% of germination at 21 days of water stress (Pereira et al., 2016). The differences observed in the rate of deterioration between seeds WoT and WiT may be associated with the presence of soil pathogens, since the sowing of soybean seeds in dry soils, or under low temperature conditions, expose the seeds for longer to the deleterious action of soil fungi, such as *Rhizoctonia solani, Fusarium* spp. and *Aspergillus* spp. (mainly *A. flavus*), which can cause their deterioration in the soil, or the death of seedlings, as described by França-Neto et al. (2016). Similar results were obtained by Peske and Delouche (1985), when evaluating different products used in seed treatment (ST) and sowing soybean under conditions of dry soil, with different textures. Rezende et al. (2003) found that there was a beneficial effect of ST on germination in sowing performed in dry soil, because the seeds maintained their viability at acceptable levels for 4 to 12 days, depending on the vigor level of the seeds used. This situation was confirmed in studies in which the ideal water availability for germination was provided for 4 to 12 days (Pereira et al., 1993) and for 7 to 15 days after sowing (Goulart, 2005). Water deficit is one of the main limiting factors of germination, and for each species there is a value of water potential below which germination does not occur (Marcos-Filho, 2015); soybean seeds show rapid hydration in the first 12 hours of the imbibition process, reaching levels close to 300 g.kg^{-1} seed (Villela et al., 2007).

Among the experiments, considering the absolute values, the highest rates of deterioration under the CTS condition are due, in part, to the higher elevation of soil temperature in the seedbed, which showed daily peaks higher than 50 °C (Figure 2b) in response to air temperature peaks close to 40 °C (Figure 2a). Thus, seeds WoT sown in soil with low water availability (maximum moisture of 20%) (Figure 1a) and high temperatures under CTS had high deterioration speed, which reduced their germination capacity at a rate of 0.5 p.p.hour^{-1} of the period of permanence in the soil. As highlighted by Costa et al. (2021), seed germination comprises a succession of several ordered metabolic and

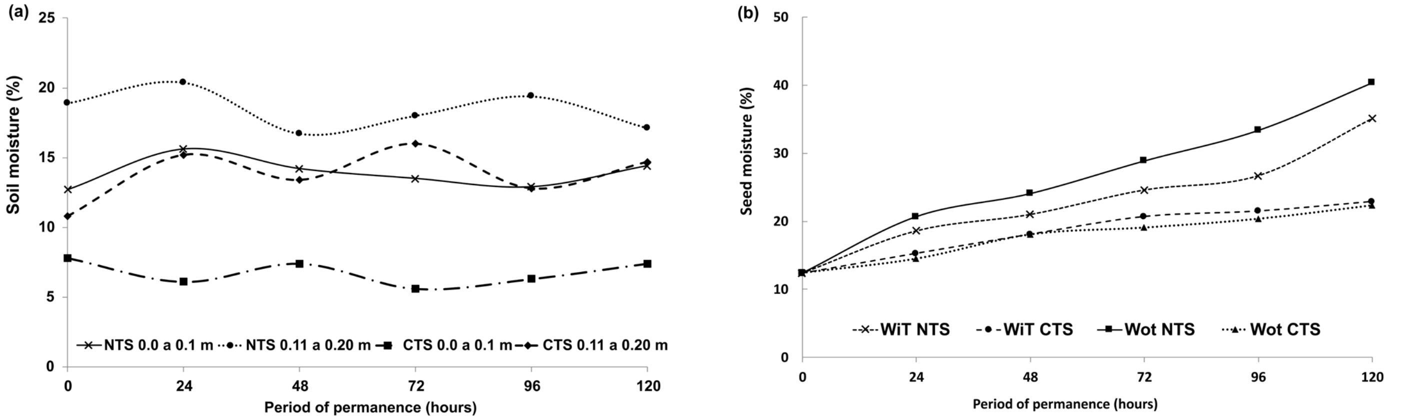

Figure 1. Data of soil moisture (a) and seed moisture (b) during the period of seed permanence in the experiments with soil management in no-tillage system (NTS) and conventional tillage system (CTS) in the 0-0.10 and 0.11-0.20 m layers.

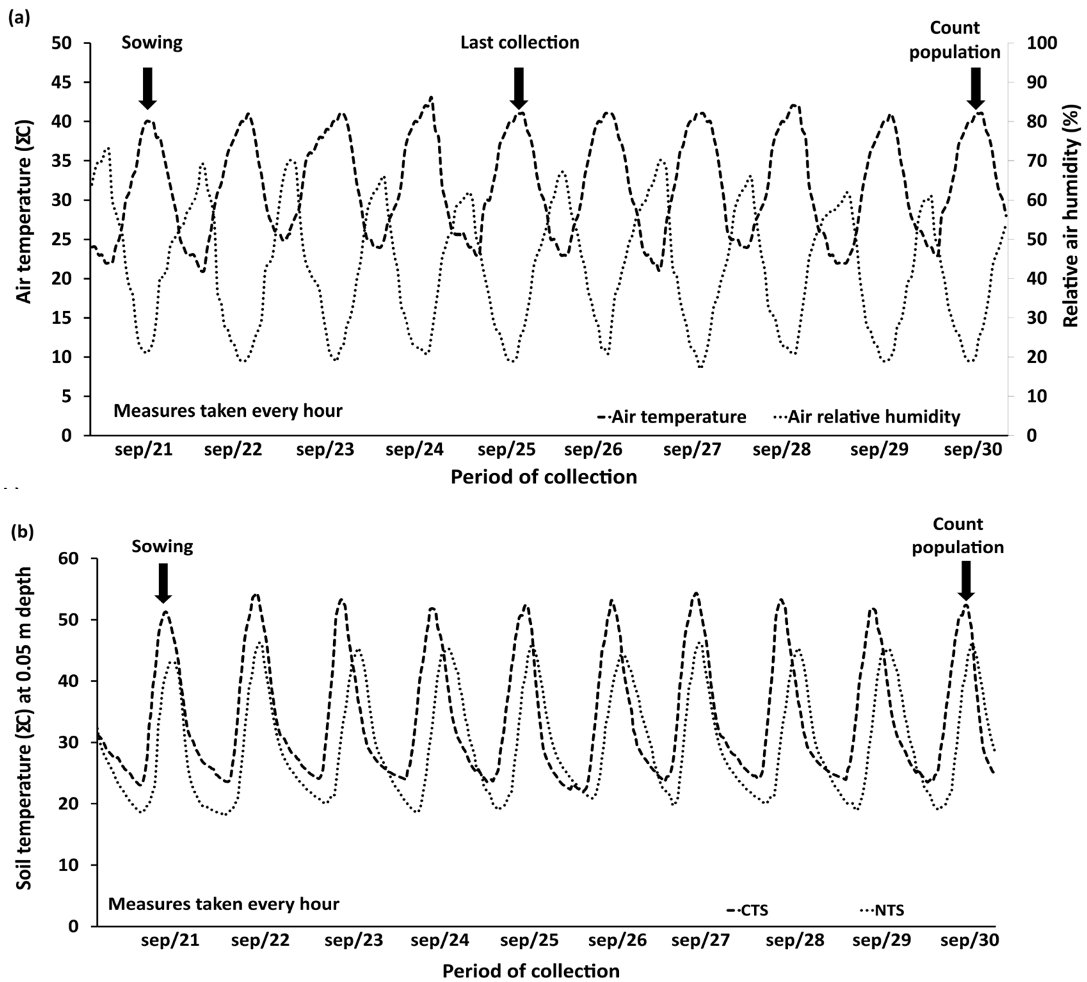

Figure 2. Daily data of temperature and relative humidity at the site of the experiments (1a); and soil temperature at 0.05 m depth (1b), in the experiments with soil management in No-Tillage System (NTS) and Conventional Tillage System (CTS).

Table 1. Summary of the significance of the analysis of variance for the variables analyzed as a function of seed treatment (ST) and periods of permanence (PP) of seeds in the soil, in the experiments under no-tillage system (NTS) and conventional tillage system (CTS).

SV	DF	NTS				CTS			
		G	V	A	D	G	V	A	D
Block	3	ns	ns	ns	ns	ns	*	ns	ns
ST	1	*	*	ns	*	*	*	ns	*
PP	5	*	*	*	*	*	*	*	*
ST x PP	5	*	*	*	*	*	*	*	*
Residual	33	---	---	---	---	---	---	---	---
Total	47	---	---	---	---	---	---	---	---
CV (%)		2.8	4.5	17.7	27.3	4.1	5.1	18.4	18.5

SV: sources of variation; DF: degrees of freedom; G: germination; V: vigor; A: abnormal seedlings; D: dead seeds.

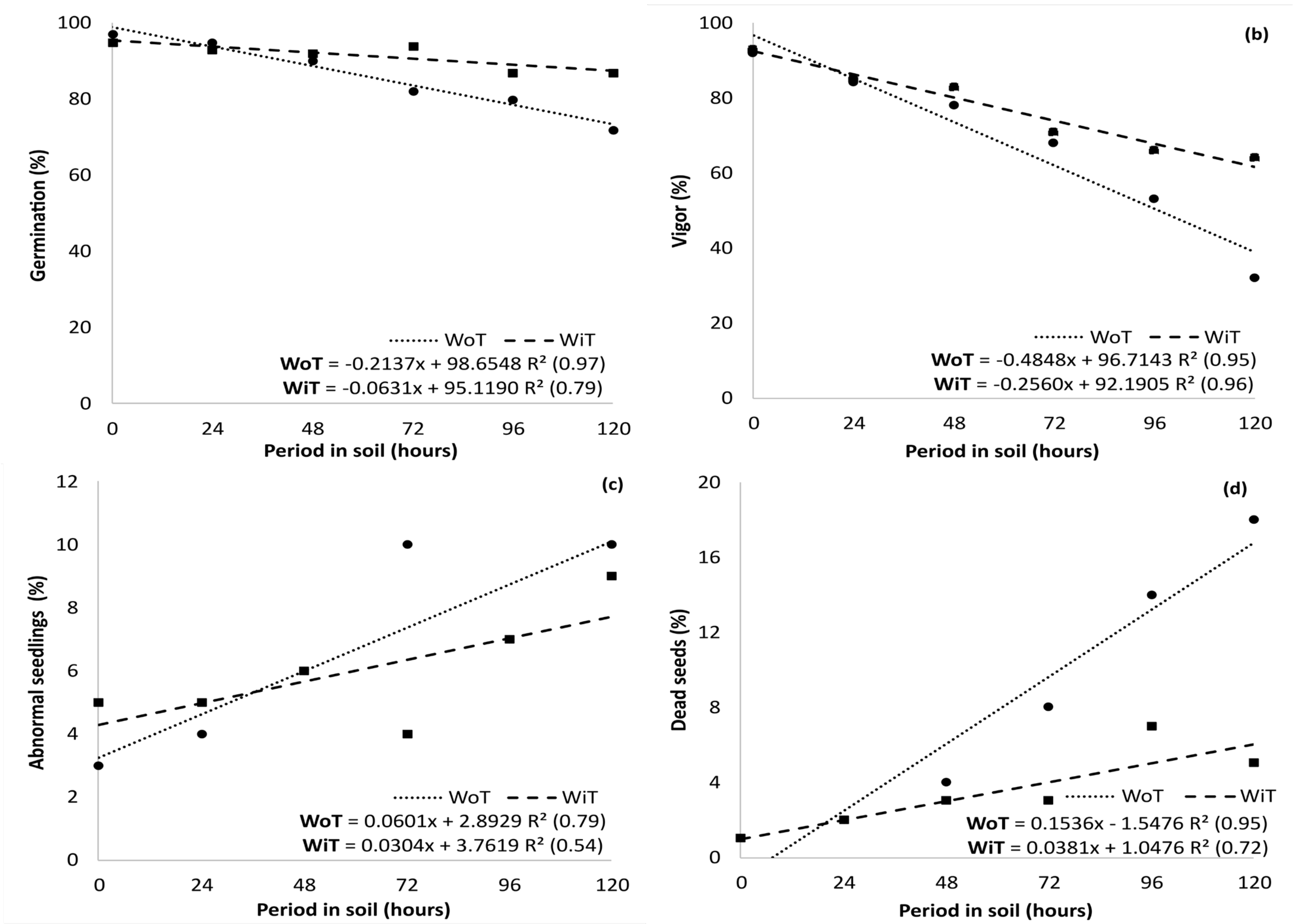

Figure 3. Germination (a), vigor (classification of seedlings) (b), abnormal seedlings (c) and dead seeds (d) as a function of the periods of permanence of seeds in the soil in the no-tillage system (NTS), for seeds with treatment (WiT) or without treatment (WoT).

biochemical phases, which characterize the resumption of embryo growth, generating a new seedling, and the success of this process is dependent on favorable environmental conditions, especially temperature and water availability, in addition to the efficiency of the cellular machinery to mobilize the energy reserves stored in the seed tissues. Therefore, under non-ideal conditions, during the process of seed deterioration there are reductions in protein content and synthesis, increase in amino acid content, decrease in soluble protein content and denaturation caused by high temperatures (Marcos-Filho, 2015). The destabilization of membranes and proteins can be a primary consequence of high temperatures, as well as a secondary response to water deficit (Taiz and Zeiger, 2017), and these environmental factors are usually found under conditions of sowing in dry soil, which can lead to the embryonic "death" of the seeds (Pereira et al., 2016). It is worth pointing out that the estimated germination of treated seeds after 120 h, in both experiments (Figures 3a and 4a), remained above the minimum limits established for the commercialization of soybean seeds in Brazil (Brasil, 2013) and Paraguay (SENAVE, 2021). This demonstrates the importance of ST mainly under stress conditions generated by sowing in dry soil under CTS, without soil cover. In this situation, after 5 days of permanence in the soil, followed by the supply of the ideal conditions, the estimated percentage of germination of seeds WoT was only 42%, while for seeds WiT the value was 82% (Figure 4a). In view of this result, it can be inferred that the reduction in soybean germination is greatly associated with longer exposure of the seeds to the deleterious effects of soil fungi and/or the fungi associated with seeds themselves, corroborating the results of other studies (Peske and Delouche, 1985; Pereira et al., 1993; Goulart, 2005; França-Neto et al., 2016).

For seed vigor, in both experiments (NTS and CTS), linear reductions were observed over the evaluated periods (Figures 3b and 4b). In the NTS, there were reductions of 12 and 6 p.p. under the conditions of seeds WoT (R^2: 0.95) and WiT (R^2: 0.96), for each 24 h of permanence in the soil, respectively. Under CTS, the reductions in the same period reached 13 and 8 p.p. for seeds WoT (R^2: 0.93) and WiT (R^2: 0.94), respectively. Considering the importance of the effect that the use of high vigor soybean seeds has on yield components, such as increase in the number of productive nodes, number of pods and number of seeds per plant, resulting in up to 19% increase in yield compared to low vigor seeds (Bagateli et al., 2020), the reduction of 12 and 13 p.p. of vigor for each 24-hour period represents 0.5 $p.p.hour^{-1}$, which would cause serious damage to the production performance of the crop when sown without ST, under the two soil management conditions with low water availability.

The increase in the percentage of abnormal seedlings over the evaluated periods was represented by linear equations in both experiments, except for the CTS condition and seeds WiT, for which there was no significant effect (Figures 3c and 4c). In the NTS experiment, after 120 h of permanence in the soil under conditions of low water availability, the estimated percentage of abnormal seedlings was 10 and 7% for seeds WoT (R^2: 0.79) and WiT (R^2: 0.54), respectively. In the CTS experiment, the estimated percentage of abnormal seedlings for seeds WoT in the same period was approximately 18% (R^2: 0.86). Thus, for every 24 h (one day) of permanence of seeds WoT in the soil, increments of 1 and 3 p.p. of abnormal seedlings were observed in the NTS and CTS systems, respectively. These results corroborate those reported by Pereira et al. (2017), who found a higher incidence of abnormal seedlings under the condition without ST, when evaluating soybean seeds with different levels of incidence of spots caused by *Cercospora kikuchii*, sown under water deficit conditions.

For the percentage of dead seeds, there was a linear increase in incidence, except for the CTS condition and seeds WiT, where no significant effect was observed (Figures 3d and 4d). In the NTS system and for seeds WoT, the increase in the occurrence of dead seeds was approximately 4 p.p. for each 24-hour period, while in the CTS this increase was 9 p.p. On the other hand, when the seeds were treated and sown in NTS, the seed mortality increment rate was only 1 p.p. for every 24 h. This demonstrates the positive effect of ST on the maintenance of seed viability, attenuating the stress condition caused by the greater exposure of seeds to soil fungi and/or fungi of the seed itself, when they were sown in dry soil, while waiting for the ideal moisture conditions to germinate. After 120 h (5 days) of permanence in the soil under conditions of low water availability, the seeds WoT showed estimated percentages of dead seeds of 17 and 40%, in the NTS (R^2: 0.95) and CTS (R^2: 0.92) experiments, respectively (Figures 3d and 4d).

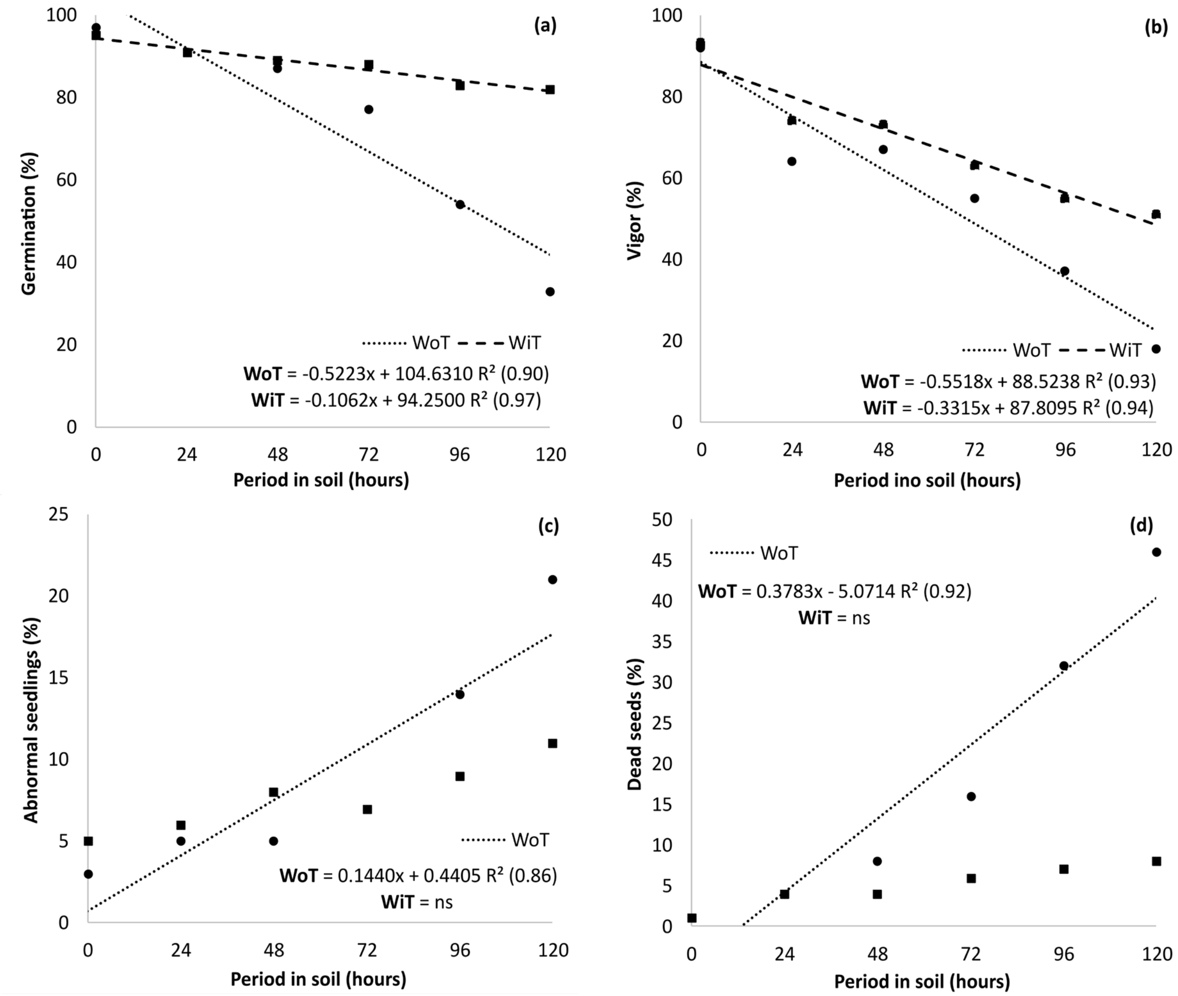

Figure 4. Germination (a), vigor (classification of seedlings) (b), abnormal seedlings (c) and dead seeds (d) as a function of the periods of permanence of seeds in the soil in the conventional tillage system (CTS), for seeds with treatment (WiT) or without treatment (WoT).

For seedling emergence, the values observed in the field were considered insufficient for proper establishment of the plantations. In the NTS management, seeds WiT resulted in 63% seedling emergence, while seeds WoT resulted in only 40%, a difference of 23 p.p. (Table 2). In the experiment under CTS, seeds WiT showed 57% seedling emergence, which represented a positive difference of 46 p.p. compared to the emergence of seeds WiT, which reached only 11%. These results may be associated with the negative impact of the high temperatures reached by the soil during the experiment, with daily peaks above 50 °C under the CTS management (Figure 2b), associated with low soil moisture, which remained below 10% in the 0-10 cm layer under the CTS (Figure 1a) and, mainly, with the lack of protection provided by the ST against fungi. In similar studies conducted in dry soils, Goulart (2005) observed an increase of 29 p.p. in seedling emergence when seeds were treated with fungicides, compared to the control without ST. The author also points out that the effect of ST was less pronounced under ideal conditions of temperature and moisture for germination, since the seeds germinated and the seedlings emerged quickly, escaping the attack of fungi from the soil and from the seed itself. In the experiment under CTS, the seeds reached a moisture content close to 20% after 120 h of permanence in the soil; in the NTS, seeds WoT and WiT reached moisture contents of approximately 35 and 40%

Table 2. Emergence of soybean plants under different soil managements, with or without the use of seed treatment.

Seed treatment	Emergence of plants (%)	
	NTS	CTS
WoT	40 b*	11 b
WiT	63 a	57 a
CV (%)	10.3	13.6

NTS: no-tillage system; CTS: conventional tillage system; WoT: without treatment; WiT: with treatment. *Means followed by the same letter in the column do not differ from each other by Tukey test at 5% significance level.

(Figure 1b). These differences in seed moisture are directly related to soil water availability in the different systems, with values in the 0-10 cm layer close to 12 and 5% under the NTS and CTS managements, respectively, and due to the higher soil temperatures in the CTS management. Despite the differences observed in soil moisture, both situations were not favorable to the soybean germination/emergence process, characterizing the condition as sowing under low water availability, popularly referred to as sowing in dry soil. As highlighted by Farias et al. (2007), soybean seed needs to absorb at least 50% of its weight in water to ensure good germination and, for this, the water content in the soil should not exceed 85% of the maximum available total or be less than 50%.

Although no statistical comparison was performed between the NTS and CTS experiments, the absolute results obtained and their relationship with the principle of the tests performed showed a beneficial effect of NTS management associated with the use of seeds WiT, confirmed by the higher germination percentages (due to the lower incidence of abnormal seedlings and dead seeds), compared to CTS and seeds WoT. Regarding vigor, adopting as practical criterion an acceptable minimum level of 75% for soybean seeds, the combination of soil management under NTS and seeds WiT ensured a good maintenance of vigor levels until 48 h of permanence of seeds in the soil (estimated value of 80%) and regular performance after 72 h (estimated value of 74%) (Figure 3b). On the other hand, the combination of CTS and seeds WoT led to the lowest percentages of germination and more marked decrease in seed vigor, reaching an estimated value of 40% of seeds dead after 120 h (Figure 4d), which would result in an inadequate stand for the good performance of soybean crop, besides increasing production costs with the need for resowing the area. However, even under the CTS management, the ST was able to maintain the germination rate at adequate levels (higher than 80%), although there were reductions in seed vigor, reinforcing the positive results of ST under inadequate sowing conditions, which prevent rapid germination and seedling emergence. Finally, when evaluating seedling emergence at 10 days after sowing, the results observed in the field were unsatisfactory in relation to the desired stand, even for the condition of management under NTS and seeds WiT.

Thus, it can be inferred that the condition of low water availability can cause extremely high losses if the soil moisture conditions are not met with rainfall within five days after sowing, varying according to the management used and the adoption or not of ST. Most of these losses may be associated with the deleterious effects of fungi, since seeds do not find ideal conditions of moisture and temperature to germinate, remaining for a longer period exposed to their negative effects. In addition, the high temperatures observed at the sowing depth (0.05 m), associated with insufficient soil moisture for the seeds to complete the germination process, favored their deterioration (Figures 1 and 2). As highlighted by Peske and Delouche (1985), under conditions of sowing in soil with very low moisture content, the loss of germination/emergence capacity increases with the increase in soil moisture, temperature and exposure time, similar to what occurs during seed storage, and the soil, even with low moisture content, is not a good site for seed storage.

CONCLUSIONS

Sowing under conditions of low water availability, although not a recommended practice, has its risk reduced if performed under no-tillage system and with seed treatment and if the ideal conditions for germination are met within five days.

Depending on management and climate conditions, sowing in soils with low water availability may lead to reductions of up to 0.2 and 0.5 percentage points per hour of exposure to dry soil in the germination and vigor of soybean seeds, respectively.

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