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Effect of fire retardants on germination of agricultural seeds

The occurrence of fires in agricultural areas grown with winter maize has become recurrent in the Central-West region of Brazil, since the harvest occurs in the dry season in the region. Fire retardants can be used as an indirect control of fire; they consisted of chemical products that can remain in the straws or on the soil after the fire extinction. The objective of this work was to evaluate the effect of two short-term fire retardants (Phos-Chek WD881® and Hold Fire®) and a hydrogel (alternative fire retardant) on germination of rice (Oryza sativa), common bean (Phaseolus vulgaris), millet (Pennisetum glaucum), maize (Zea mays), and soybean (Glycine max) seeds. The control treatment consisted of only distilled water. The seed germination percentage and speed index, mean time for germination, and seedling growth (shoot and root length and dry weight) were evaluated. A completely randomized experimental design was used, with 4 replications per treatment; each experimental unit consisted of 100 seeds maintained in germination chambers (30 °C and photoperiod of 12 hours). The effects of the fire retardants and hygroscopic polymer on the seed germination and seedling initial growth were specific, and no significant effect caused by the variations in the concentrations of the fire retardants was found.

Keywords: Germination Test; Hydrogel; Agricultural Seeds.

Efeito de retardantes de fogo sobre a germinação de espécies agrícolas

No Centro-Oeste brasileiro têm se tornado recorrente a ocorrência de incêndios em áreas agrícolas ocupadas com milho safrinha, visto que a sua colheita ocorre na estação seca da região. Como forma de combate indireto do incêndio podem ser usados retardantes de fogo, constituídos por produtos químicos que podem permanecer nas palhadas ou no solo, após a extinção do fogo. Objetivou-se avaliar o efeito de dois retardantes de fogo de curta duração (Phos-Chek WD881® e Hold Fire®) e de um hidrogel (retardante de fogo alternativo) sobre a germinação de sementes de arroz (Oryza sativa), feijão (Phaseolus vulgaris), milheto (Pennisetum glaucum), milho (Zea mays) e soja (Glycine max). O tratamento controle do foi considerado como apenas água destilada. Avaliou-se a porcentagem, tempo médio e índice de velocidade de germinação das sementes, em conjunto com o crescimento das plântulas (comprimento e massa seca da parte aérea e de raiz). Adotou-se delineamento inteiramente casualizado com 4 repetições por tratamento, sendo cada unidade experimental composta por 100 sementes, em câmaras de germinação (a 30 °C e 12 horas de fotoperíodo). Os efeitos dos retardantes e do polímero hidroretentor na germinação e crescimento inicial das plântulas foram pontuais (específicos), não sendo observados efeitos significativos com variações de concentração dos retardantes de fogo.

Palavras-chave: Teste de germinação; Hidrogel; Sementes agrícolas.

Topic: **Desenvolvimento, Sustentabilidade e Meio Ambiente**

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INTRODUCTION

The increasing demand for agricultural products generates pressures for the opening of new areas in agricultural frontiers and use of technologies to increase crop yield. Advances in the agricultural sector in Brazil, institutionally induced through public or private sectors, were decisive to make the country a large food exporter in the decade of 1990.

However, expansions of agricultural frontiers based on incorporation of areas of the Cerrado biome for agricultural production, and close to limits of the Amazon region, have been required to reach the current production levels. These expansions resulted in a concern about environmental sustainability and determined social, economic, and cultural dynamics in several regions of the states of Mato Grosso, Rondônia, Pará, Tocantins, Piauí, Bahia, and Maranhão, in Brazil (VIEIRA FILHO, 2014).

Prescribed fire is the most used method in Brazil for the opening of new areas, focused on the planting or renewal of pastures, or introduction of agricultural crops. The advantages of using fire for these purposes include the removal of vegetation from the area, production of ashes that enrich the soil the in the short-term, and stimulus for the growth of forage grass species; in addition, it is the cheapest and accessible method for small rural communities (BORGES et al., 2016).

However, the combination between the lack of techniques in the use of controlled fire and environmental factors, such as high temperatures, low relative air humidity and constant winds in dry seasons (SOARES et al., 2007) are determinant for the beginning and propagation of forest fires.

Uncontrolled fire in rural properties cause considerable economic, ecological, and social losses (OLIVEIRA et al., 2017; STEPHENS et al., 2018; VUKOMANOVIC et al., 2019). Fires have caused damages mainly in the main agricultural frontiers of Brazil, the Cerrado biome, and in Cerrado-Amazon transition areas (SANTOS et al., 2020; SIMÕES et al., 2020). Despite being adapted to and dependent on fires, the Cerrado biome, which has great ecological importance, has underwent consequences from inadequate use of fires (SILVA et al., 2011).

The occurrence of fires in agricultural areas covered with maize or cotton straws (crop residues) is another recent problem of the agricultural sector. Many problems with fires in rural properties in the whole state of Mato Grosso have been reported every crop season, since crops in this state are managed with mechanized harvest (commonly, the fire starts by the friction between machinery metallic parts or electric problems), burnable materials (straws and plants) with low moisture, and favorable weather conditions for fast propagation of fire close to noon (increase in wind bursts and air temperature and decreases in relative air humidity).

In this context, the adoption of preventive and technical actions for the control of fires is increasingly needed. In the cases of occurrence of fires in agricultural areas, several control measures are carried out to minimize the propagation, including for surrounding properties, focused on fast and efficient control; however, it can be limited by the lack of local available resources. The main practices used are implementation of firebreaks, which are not always viable (since it consists in the burning of the straw), land control (using harrows, tractors, sprayers, self-propelled sprayers), and aerial control, which depends on the availability of water in the area. The availability of water trucks and sprayers in parcels close to the harvest for the formation of wet firebreaks is among preventive measures commonly used in mechanized harvest processes.

Fire retardants for the direct or indirect control of fires are still not used for the conditions of Brazil. These products are used to increase the water extinguishing efficiency and consequently reduce the quantity of water needed, mainly in regions where this is a limited resource (FIEDLER et al., 2015).

Fire retardants are efficiency tools to optimize the control of fires (MICHALOPOULOS et al., 2016), however, the effects of these chemical products on the environment are not clear. Some damages have been reported for long-term fire retardants, such as death of plants (BELL et al., 2005), disturbances in soil microbial community (VAZQUÉZ et al., 2013; BARREIRO et al., 2010), and decreases in germination of aquatic plant species (ANGELER et al., 2004).

Few studies have approached the effects of short-term fire retardants on the vegetation, commonly characterizing them as short-term impacts, depending on the type of habitat and environmental conditions (HARTSKERLL et al., 2004; SONG et al., 2014; KEFFER, 2019; XIMENES, 2020). Contrastingly, products consolidated in agriculture have been studied as potentials fire retardants (SOUZA et al., 2012; LIMA et al., 2020a; 2020b). Hygroscopic polymers produce a gel that is efficient as fire retardants when mixed with water. The high capacity of these hydrogels to absorb water and gradually release water benefits plants by decreasing the leaching of nutrients, favoring seed germination and plant growth (NEETHU et al., 2018).

Considering the potential of fire retardants for indirect combat of agricultural fires, after knowing their impacts, the use of these products may result in significant decreases in burned area and maintenance of soil physical, chemical and biological conditions, mainly under no-tillage system. However, even if their efficiency for the control of fires is confirmed, these solutions (fire retardants + water) will be incorporated to plant residues and soil surface layer, which may affect seed germination and seedling initial development processes of subsequent agricultural crops.

Considering that fire retardants are already commercially available, Brazil needs a legislation that regulate the application of these products (IBAMA, 2018). In this context, the objective of this work was to evaluate the effect of short-term fire retardants and a hygroscopic polymer on the seed germination and seedling growth of five widely-grown agricultural species in the Central-West region of Brazil.

MATERIALS AND METHODS

Description of fire retardants

The following short-term fire retardants were evaluated: i) Phos-Chek WD881®, composed of alpha olefin sulfonate, 2,4-pentanediol, 2-methyl-, alcohol lauryl and d-limonene (ICL Performance Products LP, St. Loius, USA); ii) Hold Fire®, compose of organic oils, hygroscopic polymer, and surfactant (Favaro & Perin Ind. and Com. Ltda. ME, Vila Velha, Brazil). These fire retardants were selected due to their use and commercial availability in Brazil, and because they present specific application recommendations. The fire retardants were diluted in distilled water, at concentrations within the interval recommended by the manufacturers.

The hygroscopic polymer Nutrigel® (Agroterra Inputs, São José of Rio Preto, Brazil), which is approved as a soil water conditioner, was used as an alternative fire retardant. This hydrogel is composed of 27.8% CaO, 49.7% $CaCO_3$, 8.7% MgO, and 18.10% $MgCO_3$. The Nutrigel concentrations used were as defined by Lima et al. (2020a; 2020b), Keffer (2019) and Ximenez et al. (2021), where in field evaluations of prescribed fire in eucalyptus areas, focused on evaluating the effects of this polymer on fire dynamics and recommendation for use as a short-term fire retardants for indirect fire control.

Therefore, the treatments consisted of different concentrations of commercial fire retardants and a hygroscopic polymer: 0, 0.1, 0.3, 0.6, 0.8, and 1.0 mL L^{-1} of Phos-Chek WD881; 0, 0.7, 0.9, 1.2, 1.3, and 1.5 mL L^{-1} of Hold Fire; and 0, 0.1, 0.25, 0.50, 0.75, and 1.0 g L^{-1} of Nutrigel. The control treatment (0 mL L^{-1}) consisted of only distilled water. No comparisons between products were carried out, since they present different compositions.

Germination tests

Seeds of five agricultural species were used: rice (*Oryza sativa*), common bean (*Phaseolus vulgaris*), millet (*Pennisetum glaucum*), maize (*Zea mays*), and soybean (*Glycine max*). These species were chosen by their importance in Brazil, since soybean, maize, common bean, and rice are the grain crops with the highest planted area in the country (BRASIL, 2019); and millet has been commonly used as a soil cover crop in no-tillage system, mainly in the Cerrado biome and as a forage plant for meat and milk livestock (TRINDADE et al., 2017).

The seeds used were obtained from a seed company (Agro Norte Pesquisas e Sementes, Sinop, Brazil). The seeds were subjected to germination tests between August 2018 and May 2019, in Sinop, Mato Grosso, using germination chambers at constant temperature of 30 °C and photoperiod of 12 hours, with illumination by fluorescent lamps (2500 lux). All materials used were disinfested with sodium hypochlorite and alcohol 70% to decrease contamination by pathogens.

The germination tests were conducted in a completely randomized design with 4 replications per treatment and each replication consisted of 100 seeds. The treatments diluted in water were applied at the proportion of 2.5-fold the paper weight (BRASIL, 2009).

The seeds were placed on Germitest® paper sheets soaked with the solutions at different concentrations of the products inside Gerbox boxes with dimensions of 11×11×3 cm for the millet and rice; and in plastic germination trays with dimensions of 18×18×7 cm for common bean, maize, and soybean. The treatment solutions (fire retardants diluted in distilled water) were used to maintain the moisture, according to need of each experimental unit.

The germination percentage (G%) was determined by counting the germinated seeds after 7 days of implementation of the experiment for millet, and after 14 days for the other species, according to the Rules for Seed Analysis (BRASIL, 2009). The mean time for germination was determined by daily counts of germinated seeds from the beginning of the germination to the seventh counting (for millet), and fourteenth counting (for the other species).

The equation of Maguire (1962) was used to assess the seed germination speed index. Seeds that presented a primary root protrusion of at least 3 mm were considered as germinated.

Seedling growth

Seedling growth was evaluated considering the roots and shoot lengths, measured with a ruler (mm) at 7 (millet) and 14 (other species) days after planting. The root and of shoot dry weights were evaluated by weighing the plant parts after drying in a forced air-circulation oven at 65 °C.

Statistical analyses

The data were subjected to the Shapiro-Wilk normality test ($p \leq 0.05$) and, then, to analysis of variance (F test). Significant means were fitted to polynomial regressions at 1% and 5 % probability levels. The products were analyzed separately for each species.

RESULTS AND DISCUSSION

Fire retardant Phos-Chek WD881

The increase in the concentrations of the fire retardant Phos-Chek decreased the millet seed germination percentage and speed index. The lowest germination percentage (75.2 %) was found for the estimated concentration of 0.88 mL L^{-1}, representing a relative decrease of 15.3% when compared to the germination percentage of the control treatment (90.8%) (Figure 1a). The seed germination speed index presented a relative decrease of 16.8% when compared to the control when using the highest concentration of Phos-Chek WD881 (Figure 1b). The other species presented no significant differences.

The mean time for germination was not affected by the concentrations of Phos-Chek WD881 in any of the agricultural species evaluated (Figure 1c).

Rice seedlings presented decreases in shoot growth as the concentrations of Phos-Chek WD881 was increased. A decrease of 16.8% in shoot length was found for the control concentration, with 1.0 mL L^{-1} of Phos-Chek (Figure 2b). The fire retardant concentrations did not affect the root length of the evaluated species (Figure 2a).

Only millet presented differences in root dry weight of seedlings when subjected to concentrations of Phos-Chek WD881. The millet root dry weight decreased as the fire retardant concentrations was increased. The root dry weight found for the control treatment was 0.01 g, whereas 0.006 g was found for the highest fire retardant concentration (Figure 2c). No significant difference in shoot dry weight was found for any of the species (Figure 2d).

Millet was the most sensitive species to the concentrations of Phos-Chek WD881. High concentrations of this product may harm millet seed germination processes and rice seedling shoot growth.

Phos-Chek WD881 is composed of surfactants whose main characteristic is the decrease in water surface tension (FLORES et al., 2018). Mohammad et al. (2012) found lower root and shoot dry weights for wheat grown in pots under high concentrations of surfactants and that the effects of the surfactants are dependent on their composition and concentration.

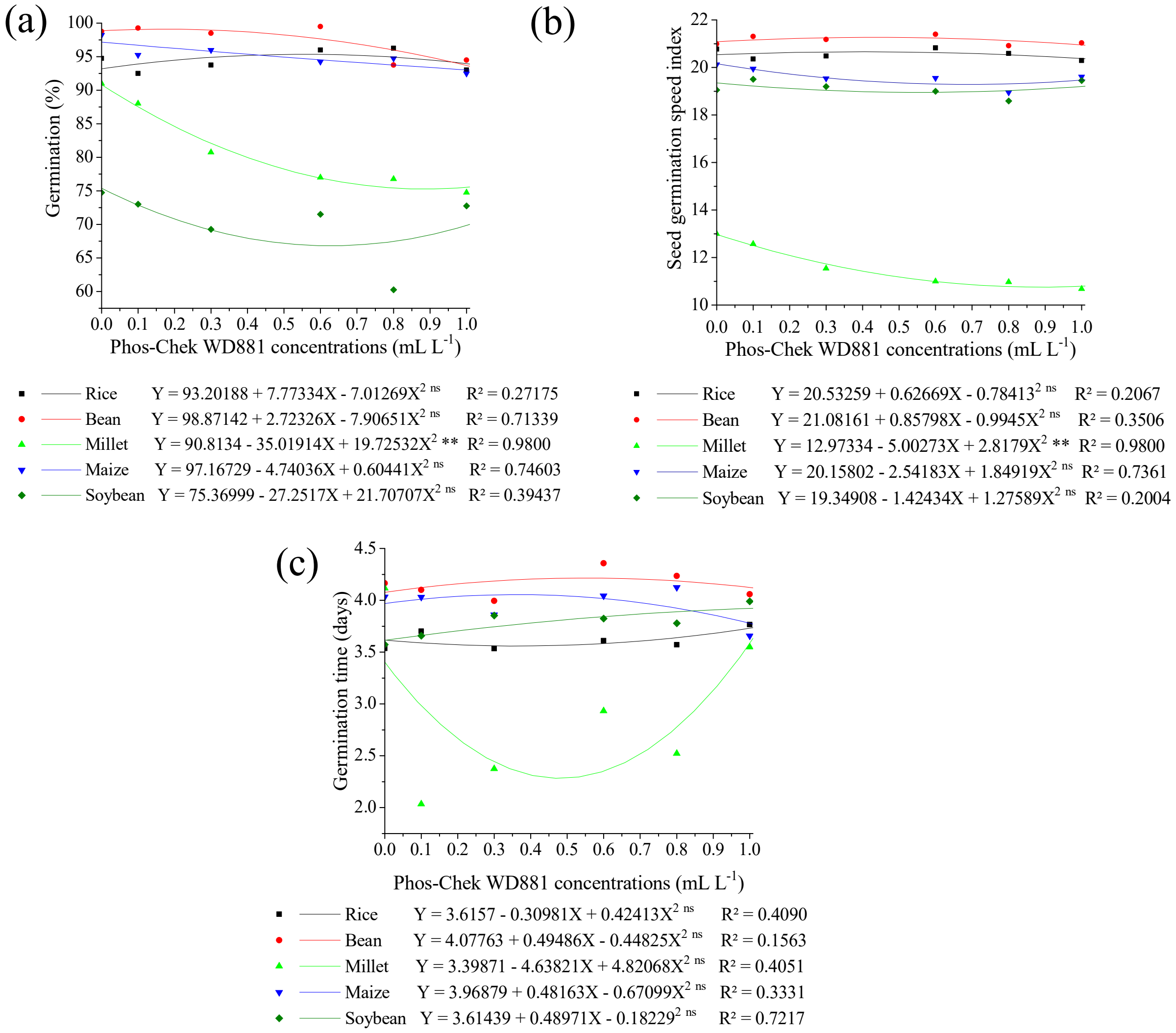

Figure 1: Seed germination (a), seed germination speed index (b), and mean time for germination (c) of agricultural species as a function of different concentrations of Phos-Chek. *** Significant at 1% probability level, * significant at 5% probability level, ^{ns} not significant.*

Changes in water surface tension by surfactants can interfere with water flows and, consequently, change shoot hydration, as found for aspen seedlings (*Populus tremuloides*) by Kamaluddin et al. (2002). This explains the decreases in shoot length of rice seedlings under concentrations of Phos-Chek WD881.

The differences in sensitivity of species to concentrations of Phos-Chek WD881 are consistent with the results of Song et al. (2014), who found that the germination rates of an herbaceous species (*Brassica campestris*) were lower than those found for a forest species, when subjected to concentrations of Phos-Chek WD881. Therefore, small seeds with thinner integuments are more vulnerable to short-term fire retardants (SONG et al., 2014).

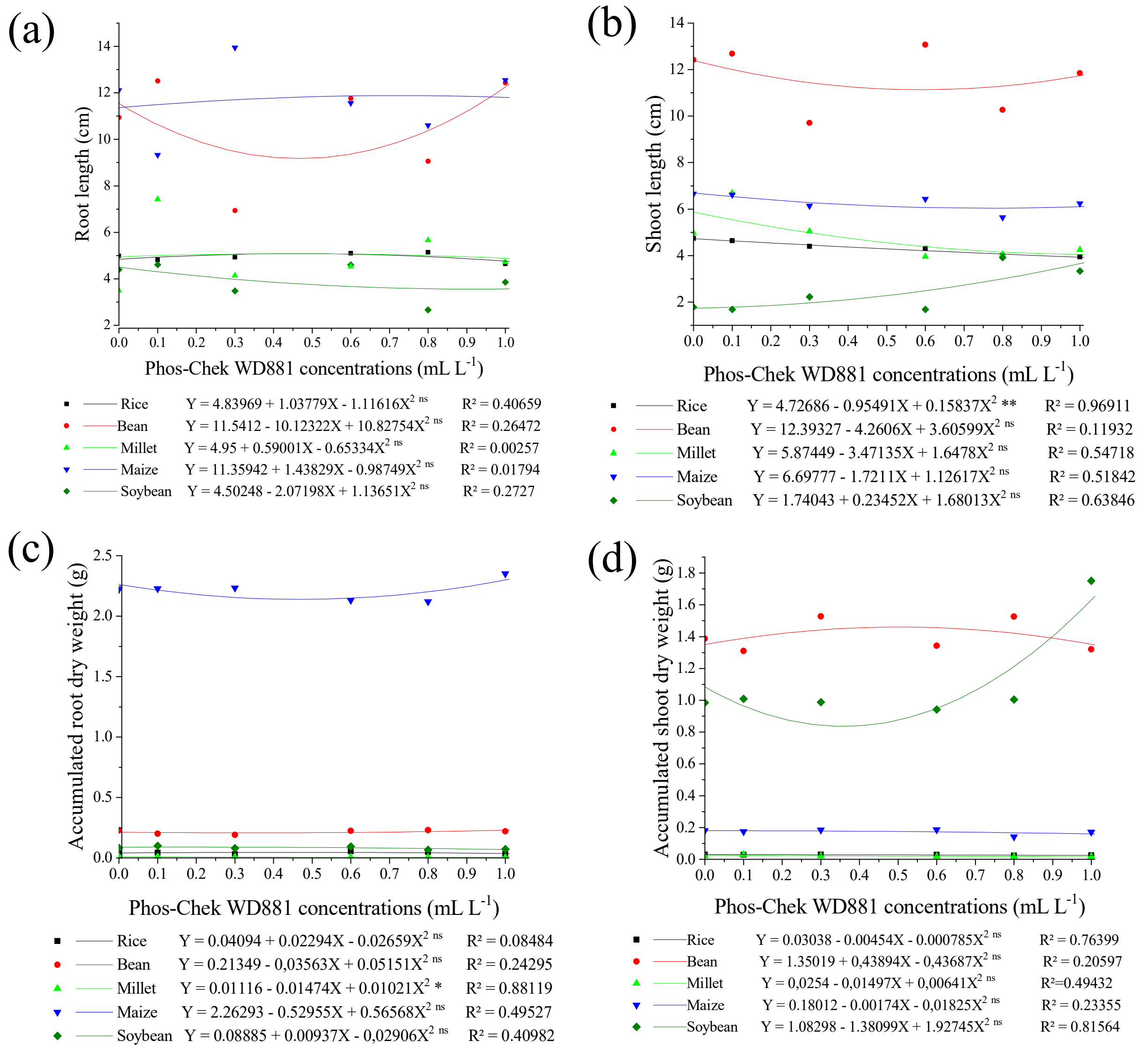

Figure 2: Root length (a), shoot length (b), accumulated root dry weight (c), and accumulated shoot dry weight (d) of seedlings of agricultural species as a function of different concentrations of Phos-Chek WD881 at 7 days after planting for millet, and at 14 days after planting for rice, common bean, maize, and soybean. *** Significant at 1% probability level, * significant at 5% probability level, ns not significant.*

Applications of Phos-Chek WD881 to combat fires close to millet and rice crop areas require strategies to avoid contaminations, since disturbances in seed germination processes can lead to irregular growth standards of plant populations. The results of the present study were obtained in a controlled environment, without effect of soil particles, solar radiation, temperature variations, and rainfall. Therefore, field experiments are needed to completely understand the plant responses to fire retardants in actual conditions.

Fire retardant Hold Fire

The effect of the concentrations of Hold Fire on germination were significant only for maize seeds. The germination percentage found for the highest concentration of Hold Fire (95.1%) was 3.7% lower than that found for the control treatment (98.8%) (Figure 3a). The seed germination speed index (Figure 3b) and mean time for germination (Figure 3c) of the evaluated species were not affected by the concentrations of the products.

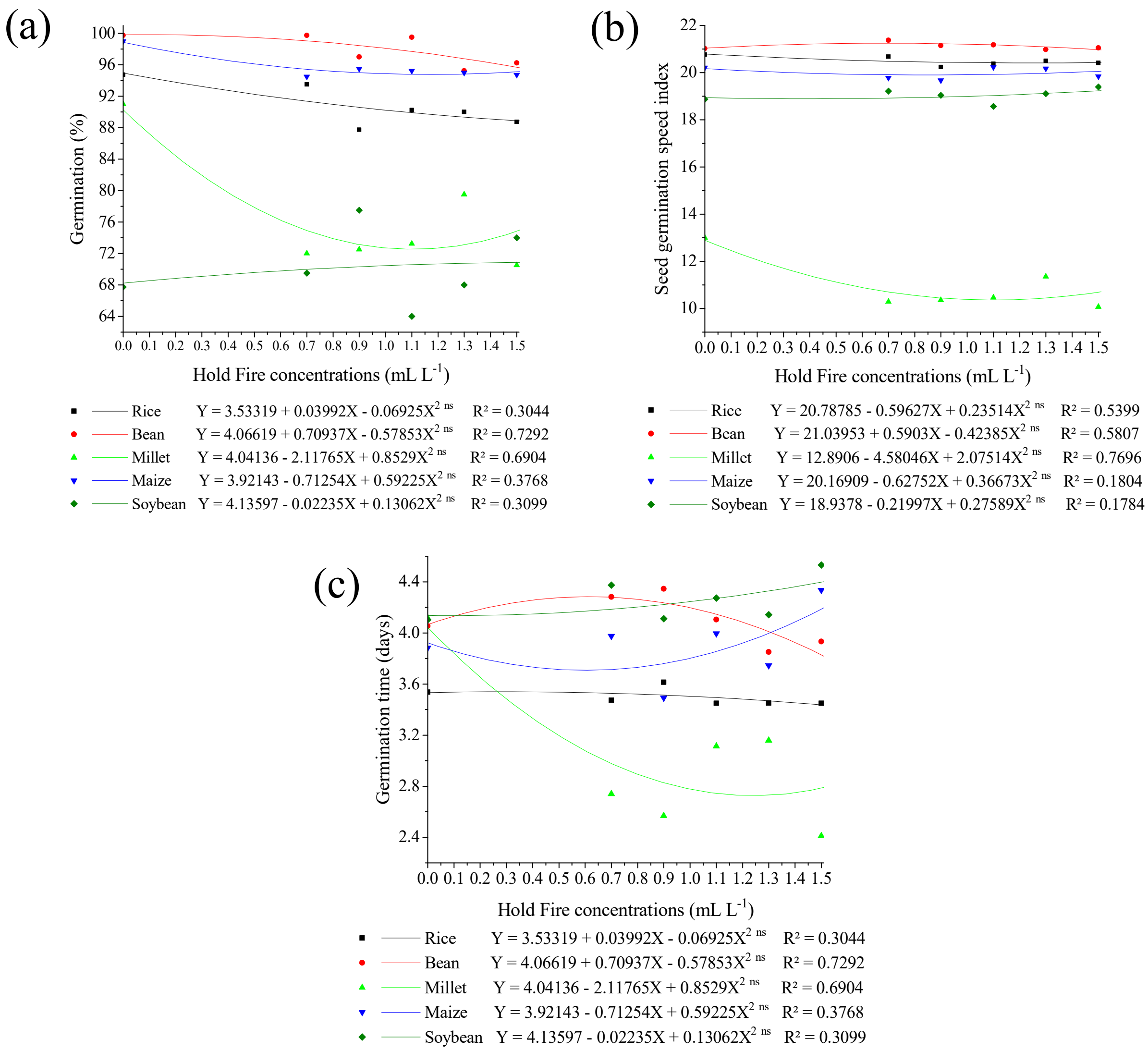

Figure 3: Seed germination (a), germination speed index (b), and mean time for germination (c) of agricultural species as a function of different concentrations of Hold Fire. *** Significant at 1% probability level, * significant at 5% probability level, ^{ns} not significant.*

The concentrations of Hold Fire had no significant effect on the root length (Figure 4a) and shoot dry weight of the evaluated species (Figure 4d), except for the shoot length of soybean seedlings. The soybean shoot growth decreased up to the estimated concentration of 0.72 mL L^{-1}, and then increased from this point (Figure 4b). The soybean and rice root dry weights decreased 32% and 38.5%, respectively, comparing to the control treatment when using the highest concentration of Hold Fire (Figure 4c).

The responses of seeds to concentrations of Hold Fire varied according to the species. According to the manufacturer, Hold Fire is a fire retardant composed of plant oils, natural hygroscopic polymer, and biodegradable surfactants. The variation in germination and root dry weight accumulation of the evaluated species may have occurred due to presence of surfactants, since they change water flows (Kalamuddin Zwiazek, 2002) as found for the Phos-Chek.

Although the increase in concentrations of Hold Fire decreased the maize seed germination, the lowest percentage found (95.1%) was still high for this species, in commercial terms. However, the use of Hold Fire may be carried out with caution, considering ecotoxicity risks to aquatic organisms, according to test results presented by the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA, 2018). Therefore, a careful application of this fire retardant in maize, rice, and soybean crop areas can avoid decreases in plant stand.

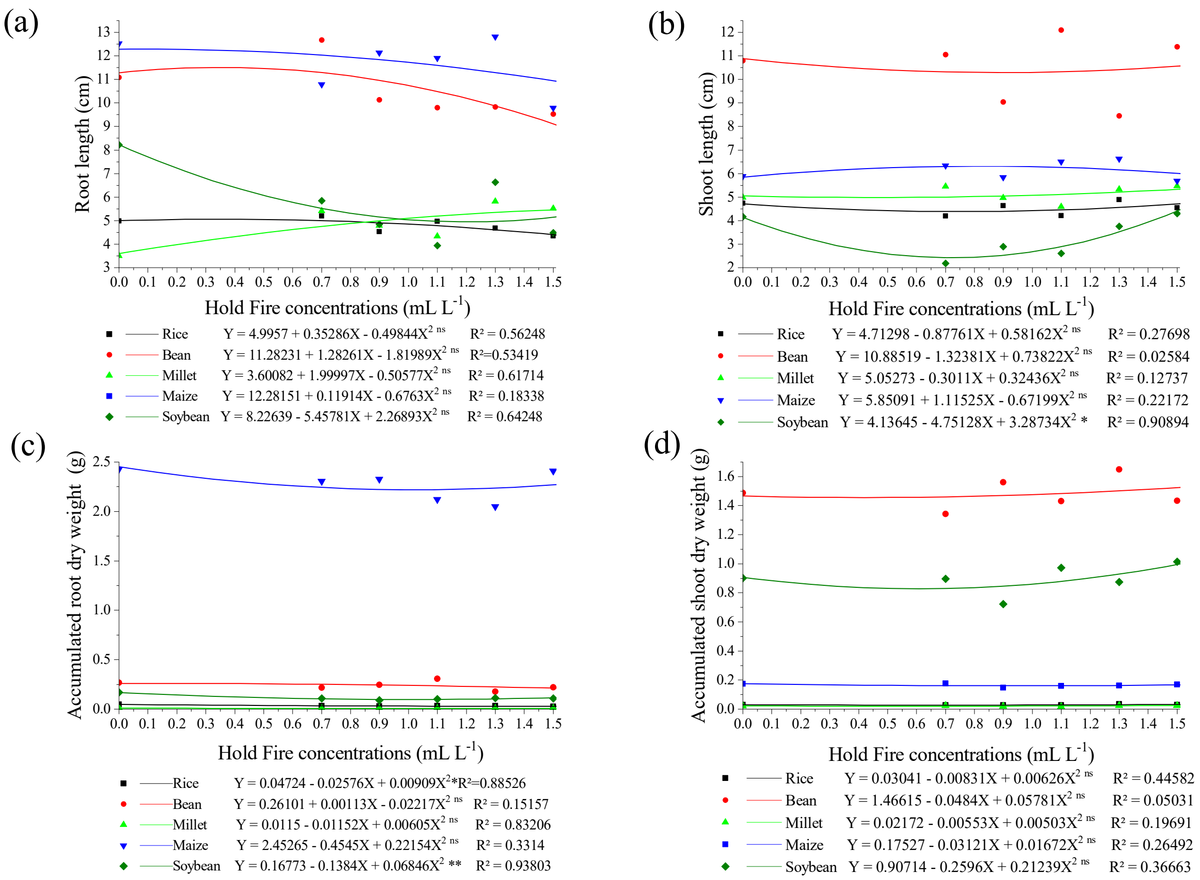

Figure 4: Root length (a), shoot length (b), accumulated root dry weight (c), and accumulated shoot dry weight (d) of seedlings of agricultural species as a function of different concentrations of Hold Fire at 7 days after planting for millet, and at 14 days after planting for rice, common bean, maize and soybean. *** Significant at 1% probability level, * significant at 5% probability level, ns not significant.*

Moreover, millet is sensitive to Phos-Chek WD881, and maize is sensitive to Hold Fire, and both are grass species of the Panicoideae subfamily. Thus, the results found for these species can be connected to the taxonomic similarity between them.

Hygroscopic Polymer Nutrigel

The soybean germination percentage decreased up to the estimated concentration of 0.76 g L^{-1} of Nutrigel, and then increased from this point. The germination of soybean seeds found for the highest concentration of hygroscopic polymer was 62.3%, whereas the control treatment presented 72.8% germination (Figure 5a). The evaluated species presented no significant differences in seed germination speed index (Figure 5b) and mean time for germination (Figure 5c) for the concentrations of Nutrigel.

The shoot length (Figure 6b) and root length and dry weight (Figure 6a and 6c) of the evaluated species were not affected by the concentrations of Nutrigel. The maize shoot dry weight tended to increase from the estimated concentration of 0.38 g L^{-1} of hydrogel. The maize dry weight for the highest concentration of Nutrigel (0.22 g) was 15.8% higher than that found for the control treatment (0.19 g) (Figure

6d).

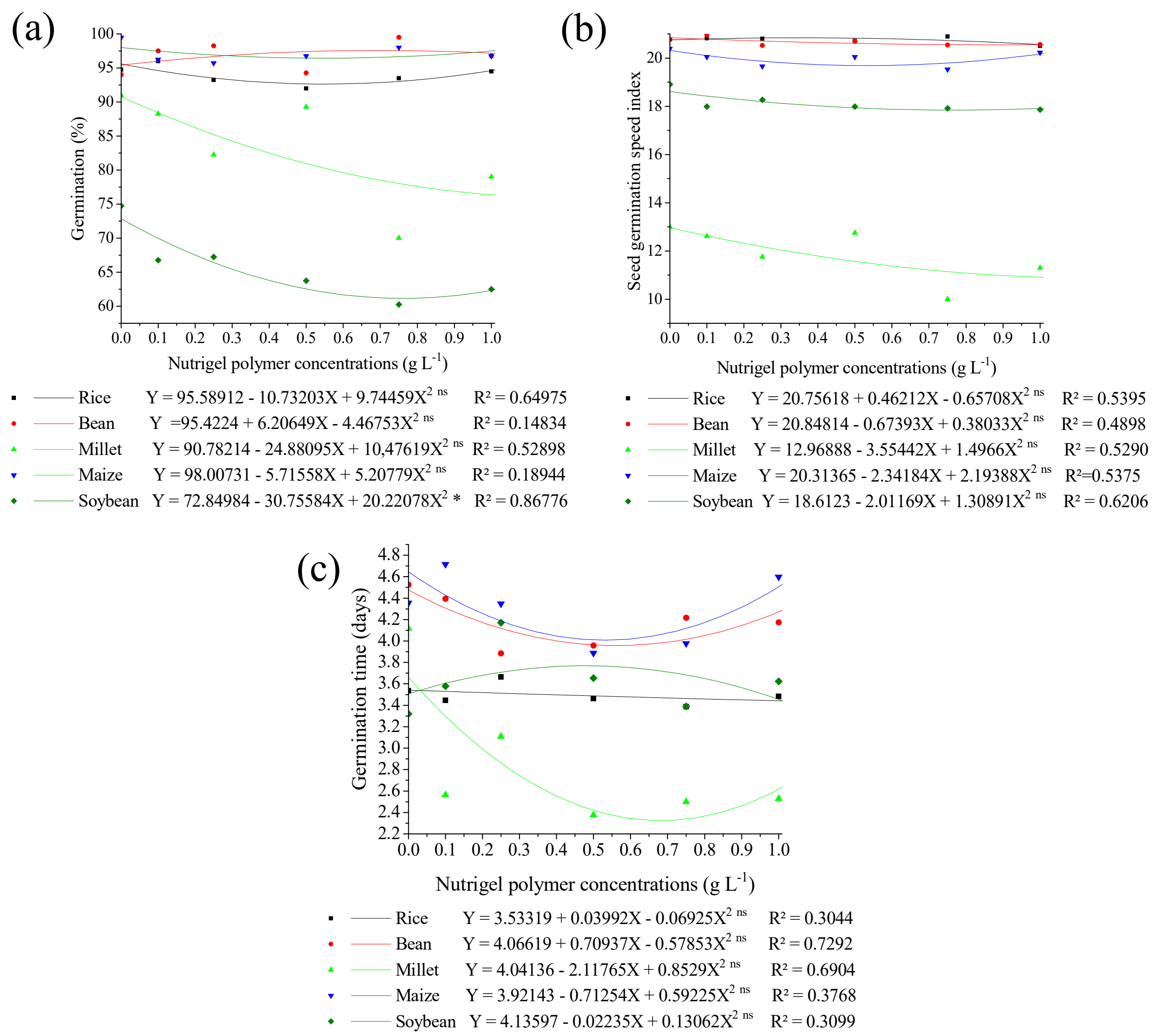

Figure 5: Seed germination (a), germination speed index (b), and mean time for germination (c) of agricultural species as a function of concentrations of Nutrigel. *** Significant at 1% probability level, * significant at 5% probability level, ns not significant.*

The use of hygroscopic polymers is an alternative to regulate water availability for crops (MENDONÇA et al., 2013). Studies have shown positive results for germination processes of some species, such as rapeseed (TANG et al., 2014), wheat, okra (SUTRADHAR et al., 2015) and maize (TAO, 2018). Moreover, the results of the present research showed increases in seed germination of soybean only when using Nutrigel at concentrations equal to or higher than 0.76 g L^{-1}. According Yonezawa et al. (2017), not only the species, but the composition and concentration of the hygroscopic polymer affect seed germination and plant development.

Pelegrin et al. (2017) found positive results for soybean plants under rates of hydrogel in field conditions. According to Neethu et al. (2018), soil permeability increases when the hydrogel is mixed to the soil and, consequently, seed germination is favored. These differences due to the environment denote the need for field evaluations of the concentrations tested in the present study.

Hydrogels used in agriculture have water absorption property, and gradually releases water according the plant demands (KALHAPURE et al., 2016). It favors seedling growth, which increases biomass accumulation, as found for the maize shoot dry weight when using Nutrigel concentrations equal to or higher than 0.38 g L^{-1}.

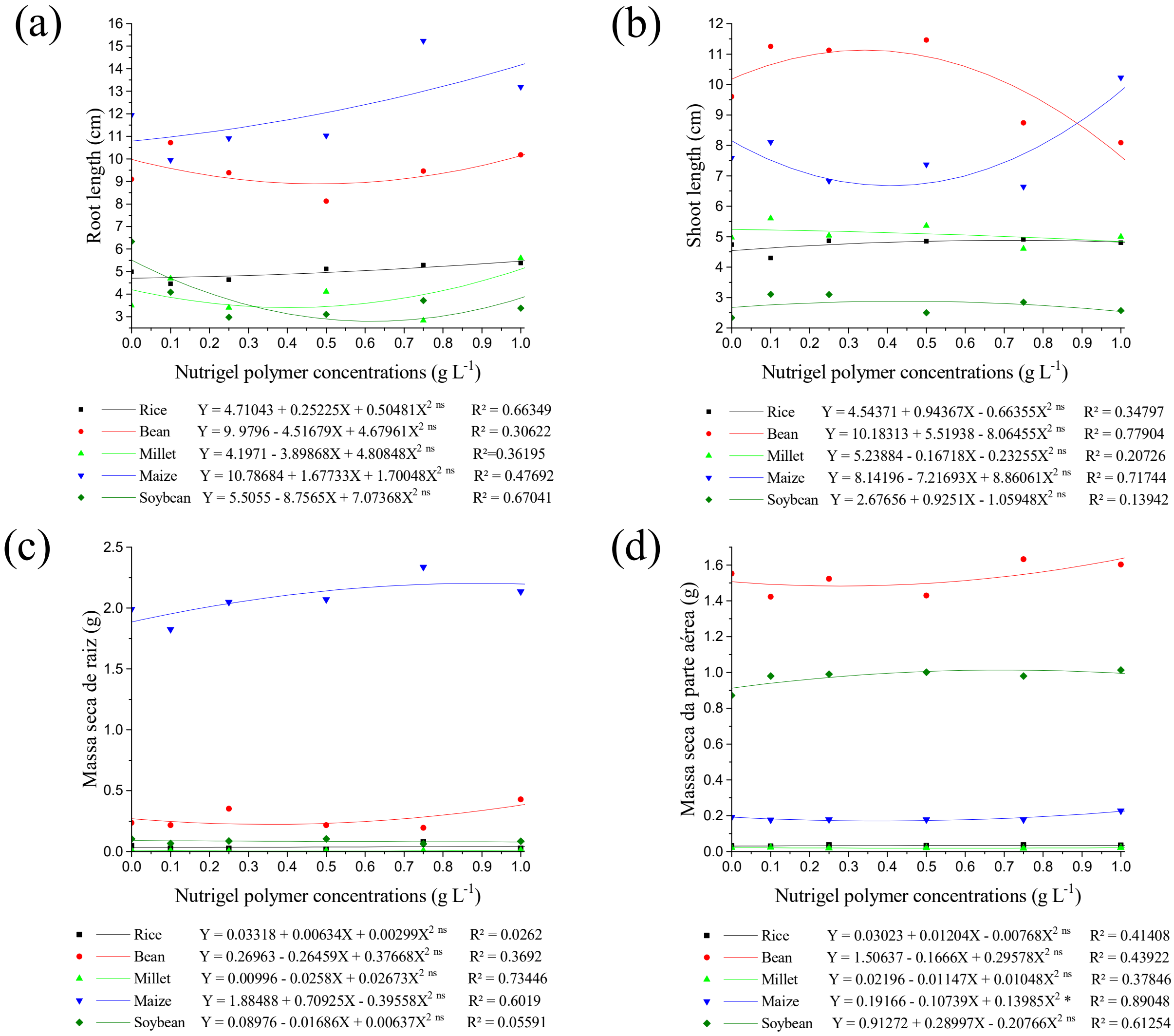

Figure 2: Root length (a), shoot length (b), accumulated root dry weight (c), and accumulated shoot dry weight (d) of seedlings of agricultural species as a function of different concentrations of Nutrigel at 7 days after planting for millet, and at 14 days after planting for rice, common bean, maize, and soybean. *** Significant at 1% probability level, * significant at 5% probability level, ns not significant.*

The Nutrigel concentrations did not affect the seed germination processes of the other species. This product is composed basically of hygroscopic polymers and calcium and magnesium carbonates; these minerals have positive effects on plant development when applied at the proper rates for each species. The use of Nutrigel as fire retardant in agricultural areas is viable when using at the concentrations tested in the present study.

CONCLUSIONS

The effect of the fire retardants Phos-Chek, Hold Fire, and Nutrigel (hygroscopic polymer) on seed germination processes and seedling growth depends on the concentration and agricultural species.

The concentrations of the fire retardant Phos-Chek used affect negatively the millet germination, vigor, and root dry weight accumulation and the rice shoot length. The concentrations of Hold Fire used decrease the maize seed germination and the rice and soybean root dry weights. The use of high concentrations of Nutrigel decreases soybean seed germination, but affects positively maize shoot dry weight accumulation.

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