Herbicide selectivity for potato crop

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ABSTRACT

Few studies on herbicide selectivity for potato crop can be found in literature, especially under Brazilian conditions. Therefore, the aim of this study was to analyze phytotoxic action of different herbicides for potato cv. Agata. Two experiments were developed under commercial field production conditions. A randomized complete block design, in factorial scheme 7x2+1, four replicates, was used, from April 14 to September 29, 2016. Treatments consisted of seven herbicides sprayed at two doses (ethoxysulfuron 45 and 90 g ha⁻¹, halosulfuron 37.5 and 75 g ha⁻¹, sulfentrazone 250 and 500 g ha⁻¹, flumioxazin 17.5 and 35 g ha⁻¹, clomazone 200 and 400 g ha⁻¹, isoxaflutole 37.5 and 75 g ha⁻¹ and oxadiazon 250 and 500 g ha⁻¹) and also a control without application. Potato plants were sprayed with post-emergence herbicide ethoxysulfuron, four and seven days after hilling up, for the first and the second experiments, respectively; the other pre-emergence herbicides were sprayed after planting. The two doses of herbicide ethoxysulfuron caused severe visual injuries to potato plants, reflected in the commercial production of tubers. However, flumioxazin, halosulfuron, sulfentrazone, clomazone, isoxaflutole and oxadiazon were considered promising pre-emergence herbicides for potato crop.

Keywords: Solanum tuberosum, cv. Agata, phytotoxicity, tolerance.

RESUMO

Estudos sobre seletividade de herbicidas para a cultura da batata são poucos, especialmente em condições brasileiras. Por isso, objetivou-se estudar a ação fitotóxica de diferentes herbicidas para a cultura da batata, cv. Agata. Dois experimentos foram desenvolvidos em área de produção comercial, no delineamento experimental de blocos ao acaso, em esquema fatorial 7x2+1, em quatro repetições, de 14 de abril a 29 de setembro de 2016. Os tratamentos foram constituídos da aplicação de sete herbicidas em duas doses (ethoxysulfuron 45 e 90 g ha⁻¹, halosulfuron 37,5 e 75 g ha⁻¹, sulfentrazone 250 e 500 g ha⁻¹, flumioxazin 17,5 e 35 g ha⁻¹, clomazone 200 e 400 g ha⁻¹, isoxaflutole 37,5 e 75 g ha⁻¹ e oxadiazon 250 e 500 g ha⁻¹), além de uma testemunha sem aplicação. O herbicida ethoxysulfuron foi pulverizado em pós-emergência nas plantas de batata, 4 e 7 dias após a realização da amontoa, respectivamente para primeiro e segundo experimento; e os demais em pré-emergência, após o plantio da batata. As duas doses de ethoxysulfuron ocasionaram injeções visuais severas às plantas de batata, com reflexo na produção comercial de tubérculos. Entretanto, flumioxazin, halosulfuron, sulfentrazone, clomazone, isoxaflutole e oxadiazon foram promissores para uso na cultura em pré-emergência.

Palavras-chave: Solanum tuberosum, cv. Agata, fitotoxicidade, tolerância.
g ha⁻¹ (Rodrigues & Almeida, 2018, Agrofit, 2019). Flumioxazin is a quite promising herbicide for this crop, based on the results in controlling solanaceous species, reported in other studies (Kazarian et al., 2000; Wilson et al., 2002; Hutchinson, 2007) and selectivity for potato crop at doses of up to 72 g ha⁻¹ (Wilson et al., 2002; Vasilakoglou et al., 2013).

Based on the control potential of problematic weeds in potato crop, ethoxysulfuron, halosulfuron, sulfentrazone and oxadiazon herbicides are recommended. The three first mentioned herbicides are excellent for cyperaceous control, such as C. rotundus (Gannon et al., 2012; Boyd, 2015); oxadiazon is effective for Oxalis spp. and solanaceous, and it is also recommended for other vegetables, such as onion and garlic (Rodrigues & Almeida 2018; Agrofit, 2019). Sulfentrazone and halosulfuron are widely studied in other countries for potato crop, for weed management and selectivity for the crop (Bailey et al., 2002, Wilson et al., 2002; Grichar et al., 2003; Hutchinson et al., 2005a,b and 2006; Boydston, 2007).

Results of weed management using herbicides is important, selectivity or its phytotoxic action in a crop of economic interest should also be considered, since the herbicide chosen should be effective for weed and selective for the crop, without affecting productive potential. Selectivity is the base for a successful chemical control of weeds in agricultural production, considering a measure of a differential response of various plant species to a given herbicide. The greater the tolerance, differences between crop and weed, the greater the application safety (Oliveira Junior & Inoue, 2011).

As variation in phytotoxic action of ethoxysulfuron, halosulfuron, sulfentrazone, flumioxazin, clomazone, isoxaflutole and oxadiazon herbicides in potato plants could be noticed, the aim of this study was to evaluate the selectivity of these herbicides for potato crop.

**MATERIAL AND METHODS**

Two experiments were conducted in the commercial production area of potato cv. Agata, in the municipalities Cristalina-GO and Unai-MG, from April 14 to September 29, 2016. Cultivar Agata was chosen for the tests for being the most planted cultivar in the country to be consumed in natura.

According to Köppen, the local climate is Aw, tropical with dry winter (Cardoso et al., 2014; Simões et al., 2015). Soil in experimental areas (16°24'35''S, 47°16'24''O, 981 m altitude and 16°5'12''S, 47°27'55''O, 970 m altitude) is representative of the region, classified as Dark-Red Latosol, presenting values of pH (CaCl₂) = 5.7 and 5.9; organic matter (g dm⁻³) = 22 and 28; P_Mehlich (mg dm⁻³) = 7.7 and 8.7; K (mg dm⁻³) = 250.0 and 155.60; Ca and Mg (cmolc dm⁻³) = 4.9 and 3.7; 1.6 and 0.9, respectively for the first and second experiment. In relation to texture, the soil in the first experiment was classified as very clayey, 610, 120 and 270 g kg⁻¹ clay, silt and sand, respectively; the soil in the second experiment was classified as clayey, 590, 368 and 42 g kg⁻¹ clay, silt and sand, respectively.

The soil was plowed once and harrowed twice, after which it was treated with a rotating hoe. Mechanized planting was performed using a planter Grimme, on April 14, 2016, in the first experiment, and July 2, 2016 in the second experiment, spacing 80 cm between lines, planting four potato seeds (type 2 and 45 mm diameter) per meter, 5 cm depth. Base fertilizations consisted of 2300 kg ha⁻¹ of NPK formulation (03-35-06). At 25 days after planting (DAP), in the first experiment, and at 27 DAP in the second experiment, cover fertilization was carried out using 350 kg ha⁻¹ NPK formulation (20-00-20). Hilling up was done simultaneously, 4 days before post-emergence application, in the first experiment and, 7 days, in the second experiment.

Plots consisted of 2.4 m width (three lines of potatoes) and 5.0 m length, with the second plot line (central position) 3.0-m length considered as useful area, totaling 2.4 m².

All plots were kept without weeds until harvest, with manual elimination of all weeds that survived chemical treatment in the control and all weeds that grew in the treatment without herbicide (control).

Potato plants were sprayed with post-emergence herbicide ethoxysulfuron, four to seven days after hilling. Pre-emergence herbicides were sprayed after potato planting. The authors used a CO₂ pressurized costal sprayer, equipped with a bar containing four spray nozzles, TTI 110015, spaced 0.5 m, with constant pressure of 3.4 kgf cm⁻², with equivalent consumption of 200 L ha⁻¹.

Due to planting time (winter season), the areas were irrigated using a center pivot irrigation system and the plants received the volume of water recommended for the crop throughout the cycle. Irrigation followed the routine of the rest of the commercial area and was performed every 48 hours, in a volume of 10 mm. In order to avoid pest and disease, insecticides and fungicides were sprayed in the experiments every week, and then the rest of the commercial area was also sprayed with these insecticides and fungicides.

Possible visual injuries in potato plants were evaluated 15, 30 and 45 days after application (DAA) of post-emergence herbicide ethoxysulfuron and 30, 45 and 60 DAA of pre-emergence other herbicides, making up the first, second and third evaluation periods, respectively; we used grading scale from 0 to 100%, in which zero represents absence of visual injuries and 100 the death of all plants in the useful area (SBCPD, 1995).

On the harvest date (August 1, 2016, in the first experiment, September 29, 2016, in the second experiment), potato plants in the useful area of plots were counted and data were estimated for plant population per hectare (hundred plants ha⁻¹). Afterwards, tubers were manually taken from the soil and, then, separated into commercial (first class: diameter >45 mm, second class: diameter: 20-44 mm, and total), and discarded, counted and weighed to obtain the quantity and fresh mass of tubers per plot. Values were estimated on ha⁻¹ and a thousand/units ha⁻¹, respectively for productivity and quantity of commercial and discarded tubers.

For commercial productivity, only
perfect tubers were considered (absence of deformation, cracks and no attacks of insects, fungi or bacteria), which showed diameter >20 mm; the others were classified as discarded tubers. Reference values of traits were estimated in relation to market trading (mainly Ceasa, DF) with the rural farmer, who lent the areas where the experiments were carried out.

In both experiments, the experimental design was randomized blocks, arranged in a factorial scheme 7x2+1, four replicates. The treatments consisted of seven herbicides applied at two doses (ethoxysulfuron 45 and 90 g ha⁻¹, halosulfuron 37.5 and 75 g ha⁻¹, sulfentrazone 250 and 500 g ha⁻¹, flumioxazin 17.5 and 35 g ha⁻¹, clomazone 200 and 400 g ha⁻¹, isoxaflutole 37.5 and 75 g ha⁻¹ and oxadiazon 250 and 500 g ha⁻¹), and one herbicide-free control, kept weed-free (manual weed picking).

Joint analysis of variance was performed using SAS statistics program v. 8.2 (Muller & Fetterman, 2003), fixed effect of both experiments (first and second) and factorial scheme of each of them were considered. The effects of experiments, herbicides, doses and their interaction, when significant, were unfolded and compared using Scott-Knott test, 5% significance level. We used the adjusted averages obtained from SAS analysis of variance to perform clustering test with the aid of Genes program Version 2013.5.1 (Cruz, 2013). Herbicide-free control was compared with treatments of interest through contrasts.

RESULTS AND DISCUSSION

ANOVA F test scores for all evaluated traits are shown in Table 1. For phytointoxication notes, significant effects of interaction between the experiments, herbicides and doses, in the three evaluation times, could be noticed. The authors decided to unfold herbicide x dose interaction in each experiment (Tables 2 and 3). In both experiments, the herbicide ethoxysulfuron, at two doses, caused severe visual injuries to potatoes, 34-65% in the first evaluation time. This is due to application, post-emergence herbicide, when the plant shoot was exposed to the product. These notes decreased over time, due to plant recovery, which was faster in the second experiment than in the first. Ethoxysulfuron was applied on July 6, in the second experiment and on May 13 in the first experiment, when the plants showed around 10 cm (in the second) and 12 cm height (in the first). The months when the herbicide was applied (May and July) affected plant recovery; this may have occurred because of weather conditions.

In another study, the authors reported that potato plants sprayed with sulfentrazone and halosulfuron, pre and post-emergence, were more sensitive to post-emergence herbicides (Gricich et al., 2003). The same was observed for sulfentrazone (Balley et al., 2002) and flumioxazin (Vasilakoglou et al., 2013) application. Applying herbicide on the plant shoot area favors higher retention and absorption, consequently, if the plant has no metabolic or biochemical selectivity to the product, harmful effects will be more drastic. This kind of selectivity allows the plant to alter or degrade the chemical structure of the herbicide through reactions which result in non-toxic substances (Oliveira Junior & Inoue, 2011).

Considering the other herbicides, only flumioxazin and the highest dose of clomazone, in the second experiment, caused phytointoxication to the crop. For flumioxazin, the symptoms were mild (less than 5%), characterized by browning of leaves, which could not be noticed anymore at 30 DAA. In another study, this herbicide also caused phytointoxication to potato plant cv. Russet Burbank, showing notes from 1 to 19%, when doses of 53, 105 and 140 g ha⁻¹ were applied in pre-emergence (Hutchinson et al., 2005b). For clomazone, phytointoxication was noticed from 45 DAA on, with

| Variation sources | Phytointoxication - time | Commercial production |
|-------------------|--------------------------|------------------------|
|                   | 1st                      | 2nd                    | 3rd                    | ɸ>45       | 20>ɸ<44    | Total      |
| Experiment        | 30.2**                   | 21.6**                 | 12.8**                 | 1.9**      | 10.1***    | 5.5*       |
| Herbicide         | 1035.8**                 | 694.1**                | 162.6**                | 3.0**      | 1.5**      | 4.4**      |
| Dose              | 22.7**                   | 95.4**                 | 24.9**                 | 0.2**      | 5.8**      | 1.4**      |
| Exp. x herbicide  | 17.9**                   | 60.6**                 | 33.3**                 | 0.2**      | 0.6**      | 0.2**      |
| Exp. x dose       | 16.4**                   | 18.1**                 | 0.2**                  | 1.4**      | 0.0**      | 1.6**      |
| Herbicide x dose  | 21.2**                   | 55.2**                 | 11.9**                 | 1.1**      | 0.9**      | 0.9**      |
| Exp. x herb. x dos.| 18.5**                  | 7.6**                  | 8.0**                  | 0.4**      | 2.3**      | 0.2**      |
| CV (%)            | 31.2                     | 36.2                   | 72.1                   | 16.3       | 30.1       | 13.5       |

ANOV A F test scores for phytointoxication notes in three evaluation times, besides production and quantity of commercial tubers (diameter >45 mm, <44 mm and total), plant population (pop.), production (Prod.) and quantity (Quant.) of discarded tuber of potato cv. Agata, in relation to experiments, herbicides, doses, interactions and factor of varieties. Cristalina-GO and Unaí-MG, Embrapa Hortaliças, 2016.

| Commercial quantity | Discarded |
|---------------------|-----------|
| Exp.               | 142.2***  |
| Herbicide           | 2.7**     |
| Dose                | 0.2ns     |
| Exp. x herbicide    | 1.2*      |
| Exp. x dose         | 1.2*      |
| Herbicide x dose    | 0.4ns     |
| Exp. x herb. x dos. | 2.3*      |
| CV (%)              | 34.9      |

**At 15, 30 and 45 days after application (DAA) of post-emergence ethoxysulfuron; and at 30, 45 and 60 DAA application of other herbicides, pre-emergence application. ** Significant at 1% and 5% probability, respectively, using ANOVA F test. *not significant using ANOVA F test.
notes ranging from 14% (45 DAA) to 12% (60 DAA), and symptoms were characterized by chlorotic spots among leaf veins. Visual damages might have occurred late, since with plant developing, the roots had access to herbicide in soil profile. Clomazone and flumioxazin movement through soil profile should also be considered, high and small, respectively. High clomazone and small flumioxazin movements through soil profile should also be considered. Herbicide movement in soil depends on the soil physico-chemical characteristics and climatic conditions.

In most cases, tolerance or susceptibility of a plant to herbicides varies depending on the product (independently of the mechanism of action or chemical group), is associated with application time (pre or post-emergence), dose used, plant size at application time (for post-emergence), characteristics of soil and plant (related to absorption, translocation and metabolism of herbicide, alteration of plant of action, etc.) (Oliveira Junior & Inoue, 2011). In this sense, herbicides ethoxysulfuron and halosulfuron inhibit the enzyme acetolactate synthase (ALS) and belong to chemical group sulfonylureas (Rodrigues & Almeida, 2018). Flumioxazin, oxadiazon and sulfentrazone have the same mechanism of action [protoporphyrinogen oxidase enzyme inhibitors (PPO)], belonging to different chemical groups, though n-fenilftalimidas, oxadiazoles and triazolinones, respectively (Rodrigues & Almeida, 2018). The same for clomazone and isoxaflutole, which are inhibitors of carotenoid synthesis, belong to isoxazolidinones and isoxazoles chemical groups, respectively (Rodrigues & Almeida, 2018).

Interaction of the three factors was also significant for quantity of discarded tubers (Table 3). In the first experiment, the highest doses of herbicide ethoxysulfuron and halosulfuron differed from the others and their respective lowest doses. The same was observed for the lowest dose of sulfentrazone. These treatments differed from herbicide-free control and resulted in lower quantity of discarded tubers. On the other hand, in the second experiment, at these two doses, no significant difference between herbicides and the control was observed. In relation to discarded tubers, in both experiments, interactions and isolated factors were not significant.

### Table 2. Averages of phytointoxication notes of the first and second evaluation times of potato cv. Agata, in relation to unfolded triple interaction (experiment x herbicide x doses), and herbicide-free control. Cristalina-GO and Unaí-MG, Embrapa Hortaliças, 2016.

| Herbicides/control | 1st evaluation - Phytointoxication (%) | 2nd evaluation - Phytointoxication (%) |
|--------------------|----------------------------------------|----------------------------------------|
|                    | 1st research (Unaí) | 2nd research (Cristalina)             | 1st research (Unaí) | 2nd research (Cristalina)             |
|                    | Lower | Higher | Lower | Higher | Lower | Higher | Lower | Higher |
| Ethoxysulfuron     | 63.8 b A (2) | 65.0 b A | 33.8 b A | 65.0 b B | 41.2 b A | 57.5 b B | 15.0 b A | 42.5 b B |
| Halosulfuron       | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |
| Sulfentrazone      | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |
| Flumioxazin        | 3.8 a A | 5.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |
| Clomazone          | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |
| Isoxaflutole       | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |
| Oxadiazon          | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A | 0.0 a A |

1At 15 and 30 days after (DAA) post-emergence application of ethoxysulfuron; and at 30 and 45 DAA pre-emergence application of other herbicides. 2Using Scott-Knott test at 5% probability, averages followed by uppercase letter, in columns, compare herbicides within each dose and uppercase letter, in lines, compare doses within each herbicide, for the respective evaluated variable.
Table 3. Averages of phytointoxication notes of third evaluation time and quantity of discarded tubers of potato cv. Agata, in relation to unfolding of the triple interaction (experiment x herbicide x doses), and control without application. Cristalina-GO and Unai-MG, Embrapa Hortaliças, 2016.

| Herbicides/ control | 3rd evaluation - Phytointoxication (%) | 1st research (Unai) | 2nd research (Cristalina) |
|---------------------|-----------------------------------------|----------------------|---------------------------|
|                     |                                        | Doses                |                          |
|                     |                                        | Lower                | Higher                   |
| Ethoxysulfuron      | 25.0 b A<sup>(2)</sup> 46.2 b B         | 12.5 b a             | 17.5 c B                 |
| Halosulfuron        | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |
| Sulfentrazone       | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |
| Flumioxazin         | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |
| Clomazone           | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |
| Isoxaflutole        | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |
| Oxadiazon           | 0.0 a A                                | 0.0 a A              | 0.0 a A                  |

Differences between the experiments are justified due to planting time (April, in the first, and June, in the second), which affected cultivar Agata. Seed potato size and form of planting could also explain those differences. Nevertheless, seed potatoes of the same caliber were used in both experiments (type 2), mechanic planting using the planter Grimme. As observed for herbicide treatments, the number of commercial tubers was more responsive to studied factors than fresh mass (production) of tubers, since the response variability was higher.

The hypothesis that there is a variation in the phytotoxic action of the herbicides ethoxysulfuron, halosulfuron, sulfentrazone, flumioxazin, clomazone, isoxaflutole and oxadiazon on potato crop was confirmed for ethoxysulfuron, flumioxazin and clomazone for phytotoxicity symptoms on potato; ethoxysulfuron, for production and quantity of commercial tubers; halosulfuron and sulfentrazone for quantity of smaller and total commercial tubers. Considering total production of commercial tubers and tubers with higher diameter, plant response to ethoxysulfuron was more pronounced and relevant, justified by the time of herbicide application (post-emergence application).

Based on phytotoxicity notes and production of commercial tubers (especially, total and diameter higher than 45 mm), the herbicides flumioxazin, halosulfuron, sulfentrazone, clomazone, isoxaflutole and oxadiazon, at two tested doses, were considered selective.
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Table 4. Averages of production (diameter >45 mm and total) and quantity of commercial tubers (diameter >45 mm, <44 mm and total) of potato cv. Agata, in relation to herbicides (isolated factor), and herbicide-free control. Cristalina-GO and Unai-MG, Embrapa Hortaliças, 2016.

| Herbicides/controls | Production (t ha⁻¹) | Qty (thousand/units ha⁻¹) |
|---------------------|----------------------|---------------------------|
|                     | ɸ<45 | Total | ɸ<45 | 20<ɸ<44 | Total |
| Ethoxysulfuron       | 39.2 b⁽¹⁾ | 45.0 b | 234.8 b | 108.2 b | 343.0 b |
| Halosulfuron         | 46.4 a | 52.7 a | 278.5 a | 99.3 b  | 377.8 b |
| Sulfentrazone        | 44.8 a | 51.1 a | 269.4 a | 110.1 b | 379.5 b |
| Flumioxazin          | 44.9 a | 51.9 a | 288.8 a | 123.1 a | 411.9 a |
| Clomazone            | 46.7 a | 53.9 a | 285.7 a | 128.9 a | 414.7 a |
| Isoxaflutole         | 48.9 a | 55.6 a | 293.5 a | 120.2 a | 413.7 a |
| Oxadiazon            | 48.6 a | 56.1 a | 287.2 a | 126.9 a | 409.3 a |
| Control              | 45.6   | 53.6   | 279.8   | 151.3   | 431.1   |

¹Using Scott-Knott test at 5% probability, averages followed by lowercase letter, in columns, compare herbicides within each evaluated variable.

Table 5. Average production (diameter <44 mm) and quantity of commercial tubers (diameter <44 mm and total) of potato cv. Agata, in relation to studied doses (isolated factor), and herbicide-free control. Cristalina-GO and Unai-MG, Embrapa Hortaliças, 2016.

| Doses/controls | Production (t ha⁻¹) | Qty (thousand/units ha⁻¹) |
|----------------|----------------------|---------------------------|
|                | 20>ɸ<44 | 20<ɸ<44 | Total |
| Lower          | 7.2 a⁽¹⁾ | 124.8 a | 403.9 a |
| Higher         | 6.2 b   | 108.5 b | 381.9 b |
| Control        | 8.0     | 151.3   | 431.1   |

¹Using Scott-Knott test at 5% probability, averages followed by lowercase letter, in columns, compare doses within each evaluated variable.

Table 6. Averages of plant population, production (diameter <44 mm and total) and quantity of commercial tubers (diameter >45, <44 mm and total) of potato cv. Agata, in relation to experiments carried out in Unai, MG (first) and Cristalina, GO (second), and herbicide-free controls of each experiment. Cristalina-GO and Unai-MG, Embrapa Hortaliças, 2016.

| Experiments | Population | Production (t ha⁻¹) | Qty (thousand/units ha⁻¹) |
|-------------|------------|----------------------|---------------------------|
|             | 20>ɸ<44 | ɸ>45 | 20<ɸ<44 | Total |
| First       | 44.8 a   | 6.1 b  | 50.8 b  | 302.4 a | 129.9 a | 431.1 a |
| Second      | 42.5 b   | 7.3 a  | 53.9 a  | 251.3 a | 103.4 b | 354.7 b |
| Control 1ˢᵗ | 42.9     | 7.68   | 52.8    | 305.4 a | 183.9   | 489.3   |
| Control 2ⁿᵈ | 44.8     | 8.36   | 54.4    | 254.2   | 118.8   | 372.9   |

¹Using Scott-Knott test at 5% probability, averages followed by lowercase letter, in columns, compare experiments within each evaluated variable.

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