NOTA CIENTÍFICA

PHYSIOLOGICAL QUALITY OF SOYBEAN AND WHEAT SEEDS PRODUCED WITH ALTERNATIVE POTASSIUM SOURCES

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ABSTRACT - The use of unconventional sources of K for plants has been widely studied, but the effects of alternative materials on physiological seed quality are still relatively unknown. The objective of this study was to evaluate the physiological quality of soybean and wheat seeds after using different potassium sources in a crop succession. The experimental design was a completely randomized block with four replications. Treatments consisted of three K sources (KCl, alkaline rock and ground phonolite, with 58%, 11% and 8.42% of K_2O, respectively) applied in four doses (0, 25, 50 and 100 kg K_2O ha^{-1}). Potassium doses were applied in soybean and their residual effects were evaluated on the following wheat crop. Soybean and wheat seeds were evaluated immediately after harvesting by tests for moisture content, seed weight, germination, first count, electrical conductivity, seedling length and seedling dry matter. Soybean plants fertilized with alternative sources of K produced heavier seeds with a lower coat permeability compared to KCl; the physiological quality of soybean seeds and the weight of wheat seeds increase due to higher K_2O doses, independently of their source.

Index terms: *Glycine max*, *Triticum aestivum*, germination, potassic rock, residual effects, plant nutrition.

QUALIDADE FISIOLÓGICA DE SEMENTES DE SOJA E TRIGO PRODUZIDAS COM FONTES ALTERNATIVAS DE POTÁSSIO

RESUMO - O uso de fontes não convencionais para fornecimento de K às plantas tem sido amplamente estudado, mas os efeitos de materiais alternativos na qualidade fisiológica das sementes não são conhecidos. Este estudo teve como objetivo avaliar a qualidade fisiológica de sementes de soja e trigo em função da aplicação fontes de potássio em uma sucessão de culturas. O delineamento experimental foi o de blocos ao acaso com quatro repetições. Os tratamentos constaram de três fontes de K (KCl, rocha alcalina e fonolito moído, com 58%, 11% e 8.42%

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de K_2O, respectivamente) aplicados em quatro doses (0, 25, 50 e 100 kg K_2O ha^{-1}). As doses de potássio foram aplicadas na soja e seu efeito residual foi avaliado na cultura do trigo, cultivado em sucessão. Logo após a colheita, as sementes de soja e trigo foram avaliadas pelos testes de teor de água, massa de sementes, germinação, primeira contagem, condutividade elétrica, comprimento de plântulas e massa da matéria seca de plântulas. Plantas de soja adubadas com fontes alternativas para fornecimento de K produzem sementes com maior massa e menor permeabilidade de membranas comparado às com KCl; maior qualidade fisiológica de sementes de soja e massa de sementes de trigo são obtidas com maiores doses de K_2O independente da fonte.

Termos para indexação: *Glycine max*, *Triticum aestivum*, germinação, rocha potássica, efeito residual.

INTRODUCTION

Potassium (K) plays an important role in seed development because it increases sugar and carbohydrate accumulation (Fontes, 2001). Rosolem et al. (1984) reported that K doses and sources may directly affect seed size, which may influence physiological quality, mainly seed vigor (Rossetto et al., 1994; Carvalho and Nakagawa, 2000), whereas Gaspar et al. (1994) and Khan et al. (2004) found that K fertilization may increase seed weight.

Positive effects of K on the physiological quality of soybean seeds have been observed by many authors (Bertolin et al., 2008; Campos and Sader, 1987; França Neto et al., 1985, Jeffers et al., 1982). Jeffers et al. (1982) reported that potassium fertilization in soybeans frequently increases normal seedlings in the germination test.

Nevertheless, K fertilization responses in soybean plants can be achieved by a number of management regimes when the soil tests low for available K (Pettigrew, 2008). Jeffers et al. (1982) studying soybean production at three locations, observed high percentages of moldy and dead seeds under conditions of K deficiency, but seed germination was improved by K fertilization.

Wheat can also benefit from potassium fertilization when soil K levels are low (Chapman and Mason, 1969; Fixen et al., 1986; Sweeney et al, 2000; Singh and Sharma, 2001). Haeder and Beringer (1981), Sweeney et al. (2000) and Sharma et al. (2005) found that K increased the kernel weight, which may affect seed vigor (Carvalho and Nakagawa, 2000). Also, K fertilization is often found to elicit an increase in wheat protein and amino acid contents (Mengel et al., 1981).

After nitrogen (N), K is the second most absorbed nutrient for several crops (Marschner, 1995). As agriculture becomes more intensive, plants increasingly demand more nutrients for appropriate development (Nachtigall and Raij, 2005).

In Brazil, national industries are unable to provide all the K fertilizers needed by crops, and, therefore, most sources have been imported (Resende et al., 2006), mainly potassium chloride (KCl), from Canada, Russia, Germany and Israel (Kinpara, 2003). However, due to the release of high amounts of chlorine and the low cation retention capacity of Brazilian soils, favoring K leaching, there are issues about applying this source.

Alternative products, such as alkaline rocks that contain K and phonolite, could be applied, as with KCl. Phonolite is an igneous, volcanic (extrusive) rock of intermediate composition (between felsic and mafic), with aphanitic to porphyritic texture and is a fine-grained equivalent of nepheline syenite, which is widely distributed throughout the world. Chemically, these rocks are composed of a high percentage of K2O as well as other elements, such as Si, which is beneficial to wheat and grasses in general (Ma and Yamaji, 2006). Chemical analysis carried out according to Vieira and Silva (2009), showed that ground phonolites contain 8.42% of K_2O, 52.5% of SiO_2, 1.58% of CaO, 0.05% of P_2O_5, 20.7% of Al_2O_3 and 7.53% of Na_2O. Another source of K is the fertilizer obtained from alkaline rocks, which are molten and ground up. These rocks chemically consist of 11.0% of K_2O, 51.7% of SiO_2, 16.8% of CaO, 0.18% of P_2O_5, 16% of Al_2O_3 and 0.38% of Na_2O (Vieira and Silva, 2009).

This objective of this study was to evaluate the physiological quality of soybean and wheat seeds produced with different potassium sources in a crop succession.

MATERIAL AND METHODS

This experiment was carried out on an Oxisol (Embrapa, 1999) at Botucatu-SP, Brazil, College of Agricultural Sciences, UNESP, latitude 22º51'S, longitude 48º26'W and 740 m altitude. According to the Koeppen classification, the climate is Cwa with a dry winter and a hot, wet summer (Lombardi Neto and Drugowich, 1994). The monthly rainfall and temperatures registered in 2007 and 2008 are shown in Figure 1. Data were collected from a weather station located in a field close to the experiment.

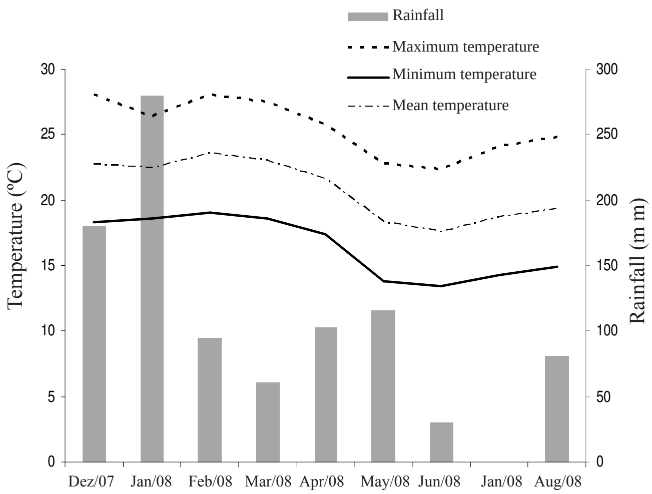

FIGURE 1. Monthly rainfall and temperatures in the experimental area.

Soil samples were taken at random from a depth of 0-0.20 m for chemical analysis, which was carried out according to methodology described by Raij et al. (2001). The results showed: pH ($CaCl_2$): 4.8; organic matter: 23 g dm^{-3}; P_{resin}: 19 mg dm^{-3}; H+Al: 55 $mmol_c$ dm^{-3}; K, Ca and Mg: 1.4, 23.5 and 13 $mmol_c$ dm^{-3}, respectively; and 41% of base saturation.

The experimental design was a randomized complete block with four replications. Treatments consisted of three K sources (KCl - 58% of K_2O, fertilizer obtained from alkaline rocks - 11% of K_2O, and ground phonolite - 8.42% of K_2O) applied in four doses (0; 0.5; 1 and 2 times the recommended K_2O dose for the soybean crop). K_2O doses to be applied on the soybeans were 0, 25, 50, and 100 kg ha^{-1}, calculated according to soil chemical analysis and the recommendations of Raij et al. (1996). Therefore, the actual doses of each material corresponded to 0, 43, 86 and 172 kg ha^{-1} of KCl; 0, 227, 454 and 908 kg ha^{-1} of the fertilizer obtained from alkaline rocks and; 0, 297, 594 and 1,188 kg ha^{-1} of ground phonolite. Soybean and wheat were cropped successively as summer and winter crops, respectively. The residual effects of these doses were evaluated on the wheat crop in succession.

The soybean cultivar 'Embrapa 48' was sown on January, 14th of 2008 over pearl millet residues, under a no-tillage system, with a 0.45-m row spacing. Late sowing was due to heavy rainfall on the days when sowing was planned. Also, the high quantities of plant residues on the soil surface did not allow machinery to work properly in the area. However, no harmful effects of the sowing date on crop development were observed. Seeds were treated with the fungicides carboxin and thiram (50 g of each of the active ingredients per 100 kg of seeds). Also, 50 kg ha^{-1} of P_2O_5 was applied in-furrow (Raij et al., 1996), as simple superphosphate. K_2O was applied three days after seedling emergence, at a single rate and 5 cm away from the plant rows. Each plot consisted of 5 rows of plants, 6 m long. The three central rows were considered as useful area, except for 0.5 m of border at each extremity. Mechanical harvesting took place on May, 5th 2008. Afterwards, the same plots were cropped with the wheat cultivar 'CD 107' grown under no-tillage, with 0.17-m row spacing on May, 12th of 2008. The six central rows were considered as useful area, except for 0.5 m of border at each extremity. Mechanical harvesting took place on August, 18th of 2008.

The soybean and wheat seeds were stored in paper bags under laboratory conditions (no temperature and relative humidity controls) immediately after harvest and were evaluated by the following tests:

Moisture content: for both crops, two subsamples of 20 seeds per field subplot were evaluated using an oven at 105 ± 3 °C for 24 h (Brasil, 1992); results were expressed as a percentage.

Seed weight: obtained by weighing four subsamples of 100 soybean seeds from each field subplot; for wheat, means were multiplied by 10 to obtain the weight of 1000 seeds (Brasil, 1992). The results were expressed in grams.

Germination: four subsamples of 50 seeds per field subplot were distributed on paper towels moistened with water equivalent to 2.5 and 2.0 times the weight of the dry paper, for soybean and wheat, respectively. The towels were rolled up and placed in plastic bags. Soybean seeds remained at the alternate temperature of 20-30 ºC whereas wheat seeds were left for germination at 20 ºC. Evaluation took place eight days after sowing (Brasil, 1992) and results were expressed as a mean percentage of normal seedlings.

First count: this was performed along with the germination test; the percentages of normal seedlings were recorded on the fifth and fourth days after sowing for soybean and wheat, respectively.

Electrical conductivity: four subsamples of 50 seeds per field subplot were weighed and soaked for 24 h at 25 ºC in 200 mL plastic cups containing 75 mL of deionized water (Vieira and Krzyzanowski, 1999); the electrical conductivity of the solution was determined using a conductivity meter Digimed CD-21 and the average values were expressed as µS cm^{-1} g^{-1}.

Seedling length: four subsamples of 10 seeds per field subplot were sown on a line drawn on paper towels moistened with water equivalent to 2.5 and 2.0 times the weight of the dry paper for soybean and wheat, respectively. The towels were rolled up and placed in plastic bags and left for germination in the upright position (Nakagawa, 1999). Soybean seeds remained in the dark at the alternate temperature of 20-30 ºC for 5 days. Wheat seeds were also left for germination in the dark at 20 ºC for 4 days. Results were obtained by dividing the weight obtained in each subsample by the number of seeds sown on the paper towel (Hampton and Tekrony, 1995) to minimize the error of low germination which could possibly lead to higher average seedling length and vice versa. Shoot, primary root and total length of seedlings were measured separately, in cm.

Seedling dry matter: after removing the remaining reserve tissues, normal soybean and wheat seedlings from the seedling length test were placed in paper bags and dried using an oven at 80 °C for 24 h (Nakagawa, 1999). Results were obtained by dividing the weight by the number of normal seedlings placed in each bag. Means were calculated for each treatment, in mg.

An analysis of variance was performed for statistical analysis. Source treatments were compared by the Tukey test ($p \leq 0.05$) and regression analysis evaluated K doses for each source, choosing the significant equations with a higher coefficient of determination.

RESULTS AND DISCUSSION

According to soil chemical analysis and interpretations from Raij et al. (1996), the potassium level was low (1.4 $mmol_c$ dm^{-3}). Therefore, positive crop responses to K fertilization were to be expected.

Many authors have found positive effects of K on seed weight and quality (Bharati et al., 1986; Khan et al., 2004). However, this study aimed to compare the effects of alternative sources of K, and KCl was considered as the control because it is the most common source of K supplied to plants.

Seed moisture contents (Table 1) for soybean and wheat did not differ statistically between each species for any of the test treatments.

TABLE 1. Moisture content of soybean and wheat seeds planted for K sources and doses.

Source	Dose (kg K_2O ha^{-1})	Moisture (%)	
		Soybeans	Wheat
Alkaline rocks	0	13.5	8.9
	25	14.2	8.9
	50	13.7	8.8
	100	13.9	8.8
Phonolite	0	13.5	8.9
	25	14.1	8.8
	50	14.6	8.9
	100	14.0	8.9
KCl	0	13.5	8.9
	25	14.2	8.9
	50	15.0	8.9
	100	14.5	8.9

The evaluation of the physiological quality of soybean seeds (Table 2) showed that seedling hypocotile length was unaffected by both the sources and doses of K. Vanzolini et al. (2007) had already reported that only the root length of soybean seedlings is more accurate for differentiating vigor levels.

A significant interaction was observed between K doses and sources for the results of seed weight and electrical conductivity (Table 2). Seeds with lower weights and higher electrical conductivity values were produced from KCl fertilization. In both tests, the sources showed similar behavior when lower doses were applied. Borkert and Yamada (2000) observed that the effects of K fertilization on seed quality are evident since seed K concentration increases with higher K rates. Therefore, there was an increase in seed quality up to a specific dose. However, at some point, as the rates were increased, the difference between the alternative sources and the KCl became significantly higher (Figure 2). Although KCl is an important source of K, Borkert et al. (1996) observed that in Paraná state, Brazil, the recommended doses applied in-furrow can harm seedling emergence and studies have shown saline stress symptoms caused by doses higher than 80 kg ha^{-1}. Conversely, the other K sources supplied for soybean development may have been more appropriate, resulting in the production of high quality seeds. One possible explanation is that these sources show high levels of SiO_2. Silicon (Si) is not considered within the group of nutrients that are essential or functional for plant growth, but Mengel and Kirkby (2001) reported that silicic acid is a precursor for lignin synthesis and thus Si application may improve seed coat development (Korndörfer and Lepsch, 2001), thus principally affecting the results of the electrical conductivity test.

TABLE 2. Analysis of variance and means of 100-seeds weight (W100, g), germination (G,%), first count (FC,%), electrical conductivity (EC, µS cm^{-1} g^{-1}), primary root length (RL, cm), hypocotyl length (HL, cm), total seedling length (TL, cm) and seedling dry matter (SDM, mg) of soybeans for K sources and doses (kg ha^{-1}).

Treatments	W100	G	FC	EC	RL	HL	TL	SDM
Dose of K_2O								
0	14.16	90	82	89.14	10.29	6.07	16.36	26.16
25	15.18	93	84	81.10	11.97	6.41	18.38	27.81
50	15.29	95	86	78.17	11.88	6.20	18.07	27.63
100	14.91	95	87	79.63	11.50	5.98	17.48	27.30
Regression	-	Q(1)	L(2)	-	Q(3)	ns	Q(4)	Q(5)
Source								
Alkaline rock	15.00 a(6)	94 a	85 a	80.11 a	11.75 a	6.28 a	18.03 a	27.05 a
Phonolite	15.03 a	94 a	85 a	80.89 a	11.30 a	6.18 a	17.48 a	27.12 a
KCl	14.62 b	92 a	83 a	85.02 b	11.17 a	6.05 a	17.21 a	27.50 a
Interaction	**	ns	ns	*	ns	ns	ns	ns
CV (%)	4.91	6.04	8.80	9.69	20.58	22.04	20.07	9.38

(1) $y = -0.001x^2 + 0.1485x + 89.973$, $R^2 = 0.99$*; (2) $y = 0.0491x + 82.6$, $R^2 = 0.90$**; (3) $y = -0.0005x^2 + 0.0589x + 10.429$, $R^2 = 0.87$**; (4) $y = -0.0006x^2 + 0.0674x + 16.551$, $R^2 = 0.81$*; (5) $y = -0.0005x^2 + 0.0554x + 26.311$, $R^2 = 0.83$**; Q stands for quadratic and L for linear regressions.
(6) Means followed by the same letter in the column to compare K sources do not differ significantly by the Tukey test ($p \leq 0.05$).
* and ** significantly different at a probability level of 5% and 1%, respectively; ns: non significant.

Independently of the source, there was a decrease in seed weight and coat permeability for higher K_2O doses (Figure 1). As the recommended dose for soybeans was about 50 kg K_2O ha^{-1}, it was observed that KCl excess reduced seed quality at higher rates. Nevertheless, seed quality maintained the increase as higher doses of the other K sources were applied. Besides K and Si supply, phonolite and alkaline rocks contain calcium (Ca), phosphorus (P) and sodium (Na). Also, there is no saline stress commonly observed for KCl fertilization.

The tests of germination, first count, root length, total seedling length and seedling dry matter revealed the effects of K_2O doses independently of the source. Quadratic equations were adjusted to all means, except for the ones from the first count test, which showed linear behavior. França Neto et al. (1985) also studied the effects of K_2O doses on the physiological quality of soybean seeds and observed higher germination and better results in the tetrazolium test for rates equal to and higher than 80 kg ha^{-1}. Although K is beneficial for the production of high quality seeds, the excessive fertilization may intensify losses due to ion leaching, even in soils with high exchangeable cation capacity (Ernani et al., 2007), such as the Oxisol in this experiment.

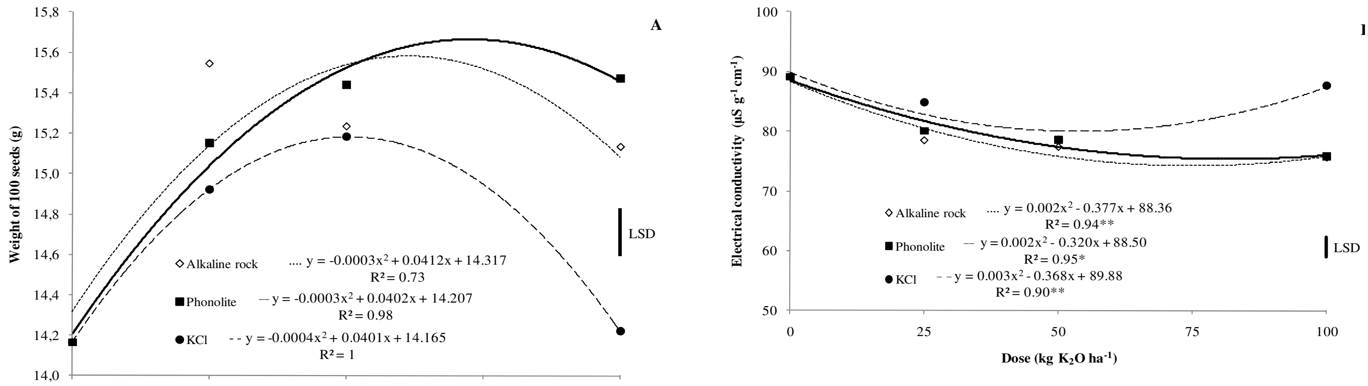

FIGURE 2. Weight (A) and electrical conductivity (B) of soybean seeds for K sources and doses.* and ** significantly different at a probability level of 5 and 1%, respectively. Vertical bars indicate least significant difference (LSD) values by the Tukey test (*p* ≤ 0.05).

There were no residual effects of K sources on wheat seed quality (Table 3) and doses did not affect seed vigor, probably because there was no application of any fertilizers directly on this crop. According to Garcia et al. (2008), potassium released by plant residues can be a significant source of this nutrient for the next crop in rotation systems, although these authors studied K levels leached from maize and *Brachiaria* residues. Nevertheless, seed weight and germination were increased by K_2O doses. Quadratic equations were adjusted to the results and showed an increase up to the recommended dose of 50 kg ha^{-1}. Khan et al. (2004) studied the effects of increasing K doses on a canola crop and found that the higher the rate applied the higher the seed weight. According to the authors, differences are generally related to a short period between anthesis and maturity and, at this time, assimilate supply to the seeds plays a crucial role in their development. Plants with higher nutrient supplies are probably at a better advantage than those with fewer nutrients (Scott et al., 1973).

Potassium is the nutrient found in higher amounts in seeds and it is important for protein metabolism and enzymatic activity (Marcos Filho, 2005). That is why all sources studied in this experiment, which provided sufficient K_2O to soybean plants, were beneficial when applied in certain doses. However, the use of both phonolite and alkaline rocks for K supply resulted in seeds with higher weights and lower coat permeability compared to KCl. Depending on the source, there were lower or higher K_2O rates that are more appropriate for crop development and high quality seed production. Doses higher than 50 kg ha^{-1} of K_2O are required when alternative sources are applied, but the responses were extremely significant and they can be much cheaper. Wheat seed quality was also affected by K doses, but not by the sources. At first, it was thought that higher K_2O rates applied previously on soybean may have increased the weight and germination of wheat seeds due to the influence of residual K in the soil. However, it is not possible to attribute the increase in seed germination to the effects of residual K, considering that the percentages of normal seedlings in the first and second counts of germination did not increase, although quadratic equations gave significant fits ($y = -0.0004x^2 + 0.0429x + 97.055$). No chemical analysis was done before wheat sowing which showed residual K levels in the soil. In this case, soybean residues may not have provided enough K to the subsequent crop, as is often observed whenever grasses are cultivated before the summer crop.

TABLE 3. Variance analysis and means of weight of 1000 seeds (W1000, g), germination (G, %), first count (FC, %), electrical conductivity (EC, μS cm^{-1} g^{-1}), primary root length (RL, cm), shoot length (SL, cm), total seedling length (TL, cm) and seedling dry matter (SDM, mg) of wheat for K sources and doses (kg ha^{-1}), as residual.

Treatments	W1000	G	FC	EC	RL	SL	TL	SDM
Dose of K_2O								
0	30.16	97	97	14.10	8.54	3.77	12.31	23.93
25	30.24	98	98	14.56	8.59	3.95	12.54	24.24
50	30.75	98	98	13.61	8.24	3.74	11.99	24.60
100	30.44	97	97	13.39	8.27	3.89	12.16	24.06
Regression	Q(1)	Q(2)	Q(2)	ns	ns	ns	ns	ns
Source								
Alkaline rock	30.39 a(3)	97 a	97 a	13.82 a	8.40 a	3.79 a	12.20 a	24.30 a
Phonolite	30.38 a	98 a	97 a	14.41 a	8.40 a	3.80 a	12.20 a	24.14 a
KCl	30.43 a	98 a	97 a	13.52 a	8.44 a	3.92 a	12.36 a	24.19 a
Interaction	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	3.93	1.52	1.61	20.63	10.13	16.42	10.67	8.16

(1) $y = -0.0001x^2 + 0.017x + 30.089$, $R^2 = 0.70$*; (2) $y = -0.0004x^2 + 0.0429x + 97.055$, $R^2 = 0.96$**; Q stands for quadratic regression.
(3) Means followed by the same letter in the column to compare K sources do not differ significantly by the Tukey test ($p \leq 0.05$).
ns: non significant.

CONCLUSIONS

Soybean plants fertilized with alternative sources of K produce heavier seeds with lower coat permeability compared to KCl.

The physiological quality of soybean seeds and the weight of wheat seeds are increased by higher K_2O doses, independently of the source.

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