ELECTRICAL CONDUCTIVITY OF THE SEED SOAKING SOLUTION AND SOYBEAN SEEDLING EMERGENCE

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ABSTRACT: Vigor of soybean [*Glycine max* (L.) Merrill] seeds can be evaluated by measuring the electrical conductivity (EC) of the seed soaking solution, which has shown a satisfactory relationship with field seedling emergence, but has not had aproper definition of range yet. This work studies the relationship between EC and soybean seedling emergence both in the field and laboratory conditions, using twenty two seed lots. Seed water content, standard germination and vigor (EC, accelerated aging and cold tests) were evaluated under laboratory conditions using -0.03; -0.20; -0.40 and -0.60 MPa matric potentials, and field seedling emergence was also observed. There was direct relationship between EC and field seedling emergence (FE). Under laboratory conditions, a decreasing relationship was found between EC and FE as water content in the substrate decreased. Relationships between these two parameters were also found when -0.03; -0.20 and -0.40 MPa matric potentials were used. EC tests can be used successfully to evaluate soybean seed vigor and identify lots with higher or lower field emergence potential.
Key words: *Glycine max*, vigor, physiological quality, water stress

CONDUTIVIDADE ELÉTRICA DA SOLUÇÃO DE EMBEBIÇÃO DE SEMENTE E EMERGÊNCIA DE PLÂNTULAS DE SOJA

RESUMO: O vigor de sementes de soja [*Glycine max* (L.) Merrill] tem sido avaliado por intermédio da medida da condutividade elétrica na solução de embebição das sementes, mostrando boa relação com a emergência de plântulas em campo. Estudou-se a relação entre os resultados do teste de condutividade elétrica e a emergência de plântulas de soja em campo e no laboratório. Vinte lotes de sementes foram submetidos aos testes de germinação, condutividade elétrica, envelhecimento acelerado e de frio, além da determinação da emergência de plântulas em campo e no laboratório, sob diferentes condições de deficiência hídrica no substrato. No laboratório, condições de deficiência hídrica foram simuladas usando-se potenciais matriciais de -0,03; -0,20; -0,40 e -0,60 MPa. Houve relação entre os resultados do teste de condutividade elétrica e os de emergência de plântulas em campo. No caso da emergência no laboratório, à medida que se diminuiu a quantidade de água no substrato houve redução na associação entre condutividade elétrica e emergência de plântulas. Foi também observada relação entre os dois parâmetros sob os potenciais matriciais de -0,03, -0,20 e -0,40 MPa. O teste de condutividade elétrica pode ser usado com sucesso na avaliação do vigor de sementes de soja e na identificação de lotes com maior ou menor potencial de emergência em campo.
Palavras-chave: *Glycine max*, vigor, qualidade fisiológica, deficiência hídrica

INTRODUCTION

Seed technology, a segment of agricultural production systems, aims to improving seed germination and vigor tests to obtain good expression for seed lot performance potential, under a broad range of field conditions. Current research target the improvement of vigor tests.

The basic objective of vigor tests is to identify significant differential physiological quality among lots of seeds with good commercial quality, particularly for those of similar germination potential. There are tests adequated to evaluate the actual seed metabolic conditions and other techniques to evaluate their performance under specific environments, mainly under stress conditions.

Among the seed vigor tests, the EC procedure has been satisfactorily used to evaluate the physiological quality of soybean seeds (AOSA, 1983; Loeffler et al., 1988; Marcos Filho et al., 1982; 1990; Hampton et al., 1992; Vieira et al., 1999a; 1999b; Vieira & Krzyzanowski, 1999). EC is a fast and practical procedure, allowing to obtain objective information; it is also easily used in most seed analysis laboratories, not requiring expensive equipment or skilled personnel. Values of EC measured in seed soaking solutions vary with leaching and is directly related to the cellular membrane integrity. Desorganized membranes, affected by insects, mechanical injury and/ or long storage periods, are usually associated to the seed deterioration processes (Bewley & Black, 1994) and consequently to lower vigor.

The relationship between laboratory and field seedling emergence tests depend directly on environmental conditions and procedures adopted for field sowing. The capacity of laboratory tests estimating field seedling emergence potential decreases with increasing deviations from the ideal environmental conditions, and becomes null under extremely unfavorable conditions (Egli & TeKrony, 1996; Marcos Filho, 1999).

Studying the EC test for pea seeds, Matthews & Powell (1981) presented a range of EC values for the classification of seed lots depending on the perspective of their utilization, that is, the utilization potential of a certain seed lot is recommended based on the EC value. In the case of soybean seeds, the range has not yet been defined, and is necessary for seed lot classification and for their respective destination, according to field environmental conditions, allowing to make inferences on the probability of success of the crop. In tropical and subtropical regions, the main field condition for such success is basically related to soil water availability. This work studied the relationship between the EC values of seed soaking solutions and soybean seedling emergence both in the field and laboratory conditions, under several water availability levels in the substrate.

MATERIAL AND METHODS

The experiment was carried out at Jaboticabal, SP, Brazil (21°15'22"S, 48°18'58"W; altitude 613.38 m), using twenty two soybean seed lots (Table 1). The following variables were evaluated for both conditions:

Seed water content: determined in intact seeds by the oven method at 105±3°C, during 24 hours, using two replications of 25-seed samples per lot, as recommended by the Rules for Testing Seeds (Brasil, 1992). Results were expressed in percent of fresh weight basis.

Standard germination: evaluated using four replications of 50-seed samples for each lot, placed on rolled paper towels moistened with water equivalent to 2.5 times the substratum weight and germinated at 25°C. Seedling counts were made 5 and 8 days after sowing (Brasil, 1992); results were expressed in percentage.

Electrical conductivity: measured on four replications of 50-seed samples per lot, weighed on an analytical balance (0.01 g) and soaked in disposable plastic cups containing 75 mL deionised water, during 24 hours at 25°C (Hampton & TeKrony, 1995; Vieira & Krzyzanowski, 1999). Readings were made using a Digimed conductivimeter CD-21.

Accelerated aging: performed on a single layer of seeds (42 g) placed on a wire mesh screen and suspended over 40 mL of distilled water inside plastic accelerated aging boxes (11.0 x 11.0 x 3.5 cm), held at 41°C and near 100% air relative humidity for 72 hours (Hampton & TeKrony, 1995; Marcos Filho, 1999). After the aging period, seeds were tested for standard germination (Brasil, 1992), and the number of normal, five day-old seedlings was evaluated.

Table 1 - Initial and after accelerated aging seed water contents, standard germination test (SGT), accelerated aging (AA), cold test(CT), electrical conductivity (EC) and field emergence (FE) of soybean seed lots.

Seed	Seed water content		SGT	Seed vigor			
	Initial	After AA		AA	CT	FE	EC
Lots	------------------	%	--------------------				µS cm^{-1} g^{-1}
1	8.4	25.3	89	94	79	91	77
2	8.5	25.4	99	93	87	89	86
3	8.6	31.2	92	87	79	88	95
4	8.7	27.4	82	81	78	84	111
5	8.1	27.0	95	90	89	91	106
6	8.1	26.3	90	80	88	89	86
7	8.9	27.3	91	79	87	83	110
8	8.2	26.0	91	89	88	84	92
9	8.7	25.7	91	88	83	91	103
10	9.1	26.6	88	82	86	87	90
11	9.7	27.0	91	74	69	86	101
12	9.2	26.9	90	81	91	88	87
13	9.2	26.0	91	77	97	86	74
14	8.2	25.5	92	85	88	85	88
15	8.1	24.8	83	63	75	74	105
16	9.8	29.1	86	88	94	91	57
17	9.7	26.2	95	83	67	86	111
18	8.3	25.1	77	66	68	74	120
19	9.7	26.9	86	84	88	88	89
20	8.9	27.3	87	72	82	79	82
21	10.9	26.8	94	74	90	82	96
22	11.3	27.3	96	81	95	93	69
Means	9.0	26.7	90	82	84	86	93
LSD(0.05)			11.4	14.3	14.3	12.3	17.6
CV(%)			4.8	6.6	6.4	6.8	7.2

Mean comparisons (LSD = least significant difference) by Tukey test at 0.05 level. Lots no.1-10 cv. Iguaçu; no.11-15 cv. IAS-5 and no.16-22 cv. Embrapa 48

Field seedling emergence: carried out in an experimental area using four replications of 50-seed samples per lot, uniformly sown in 1.5 m long and 0.25 m spaced rows. The soil was irrigated to provide sufficient water to allow seedling emergence. The number of emerged seedlings was evaluated 14 days after sowing and the results were expressed in percentage (Nakagawa, 1999).

Laboratory seedling emergence: made using four replications of 50-seed samples seeded in plastic boxes (28.5 x 18.5 x 10.0 cm) containing 3.5 kg of soil as germination substrate. Air dried, fine-textured soil samples were used from the 20 cm top layer of a euthophic Rhodic Hapludox, of an area close to the field experiment. The water tension values (matric potential) used during the test were -0.03; -0.20; -0.40 and -0.60 MPa; the soil water content, on a volume basis, correspondent to each matric potential, was calculated by the characteristic water retention curve of the soil. Based on the initial soil moisture, determined by the gravimetric method (EMBRAPA, 1997), and on the moisture of each treatment obtained from the water retention curve, the quantity of water to be added to each plastic box was determined, to establish the desired tensions and different water availability levels. The values determined for each situation were:

$Q = (\theta_c - \theta_i)$ and $V = m(Q/100)/d$

where: Q = quantity of water to be added to the soil substrate (%); θ_c = moisture, on a volume basis, corresponding to a desired water tension (%); θ_i = initial soil moisture, on a volume basis (%); V = water volume per plastic box (cm^3); m = soil mass in the plastic box (g); d = soil bulk density ($kg\ dm^{-3}$).

Once the quantity of water to be added to each plastic box was determined, the distilled water was added and carefully mixed to the soil to obtain uniformly-distributed moisture in each treatment. Therefore, the amount of water correspondent to each water stress treatment was put into small manual sprinklers and distributed over the soil, following homogenization using a soil mixer. After this procedure, the soil remained covered by a black polyethylene plastic bag during 24 hours to avoid evaporation and obtain a completely homogenized water distribution. The soil was then transferred to plastic boxes and seeded. The water stress treatment was maintained by covering each plastic box with transparent polyethylene bags (50 cm wide x 80 cm long x 0.14 mm thick) avoiding evaporation. The plastic boxes were randomly distributed over tables, under laboratory environment conditions. On the fifth day after sowing, seedling emergence was evaluated.

Statistical analysis of data was performed using a randomized block design, with four replications. Linear regression analysis was also applied to the data obtained from electrical conductivity tests and the seedling emergence means, both in field and laboratory. Multiple mean comparison was performed using the Tukey test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Most seed lots presented adequate commercial standard germination (≥ 80%), except for lot 18 (77%) (Table 1). The average percent germination was 90%. After the accelerated aging of seeds, percent germination among seed lots range between 63 and 94% (mean = 82%). Although all seed lots, except for lot 18, presented similar percent germination and were considered commercially viable, the seed vigor varied among them and consequently they were potentially different with relation to the field seed set capability (Table 1).

The initial water content of seeds varied from 8.1 to 11.3%, averaging 9.0%. After the accelerated aging, most values remained between 25.1 and 27.4%, except for lots 16 (29.1%) and 3 (31.2%). Most seed lots presented similar moisture contents, within the expected range for soybean seeds submitted to accelerated aging in germination chambers, usually varying between 25 and 30% (Bittencourt et al., 1995; Scappa Neto et al., 2000). Therefore, procedures recommended for the tests (AOSA, 1983; Hampton & TeKrony, 1995; Marcos Filho, 1999), were adequately used in this research. Despite the higher moisture content of lot 3, no effect was observed on the other test results obtained for this lot.

Concerning the cold test, most seed lots presented standard values above 80% (Table 1). Soybean seed lots that present EC test values between 60 and 70 $\mu S\ cm^{-1}\ g^{-1}$ are considered high vigor seed lots; values between 70 and 80 $\mu S\ cm^{-1}\ g^{-1}$ are presented by intermediary vigor seed lots (Vieira, 1994). On the other hand, in the United States of America, seeds with EC values higher than 150 $\mu S\ cm^{-1}\ g^{-1}$ are classified as low vigor seed lots and considered inadequate for sowing (AOSA, 1983). One of the causes for the high EC values obtained for some seed lots is, probably, the low initial seed water content (Table 1), as already reported by Tao (1978), Loeffler et al. (1988), Hampton et al. (1992) and Vieira et al. (2002). These authors observed that soybean seeds having initial water contents lower than 10% usually presented higher values for the EC test, in spite of having similar standard germination and vigor evaluated by the accelerated aging test. This has been attributed to the fact that, the lower the seed moisture content, the higher the structural desorganization of cellular membranes, and the higher the loss of lixiviates during the initial period of seed soaking and, consequently, the higher the value of EC of the seed soaking solution, which does not mean, however, a necessarily lower seed vigor (Bewley & Black, 1994). The effect of the initial seed water content is very difficult to be isolated and characterized, and may interact with other factors affecting EC.

During the field seedling emergence test, 86% of seedling emergence was observed. Seed lots 15 and 18, which had coherent results for the germination, vigor and emergence tests, presented, respectively, the lowest values for seed germination (83 and 77%), accelerated aging (63 and 66%), cold test (75 and 68%) and seedling emergence (74 and 74%), and the highest values for the EC test (105 and 120 μS cm^{-1} g^{-1}). Consequently, according to the concept of seed vigor, a lower vigor seed lot should present lower field performance potential.

Nevertheless, lots 5 and 9, having had high percent germination and vigor determined by the accelerated aging and cold tests, presented also high field seedling emergence, although their respective high EC test values had placed them as low seed vigor lots (Table 1). This fact might be related to changes in EC standards resulting from the initial seed moisture, as already reported by several authors (Tao, 1978, Loeffler et al., 1988; Hampton et al., 1992; Vieira et al., 2002). Low initial seed water content may result in high EC values, what does not necessarily mean low vigor seeds. Another reason for the occurrence of this phenomenon might be seed soaking injury (Bewley & Black, 1994) or variation in the seed tegument lignin content (Alvarez et al., 1997; Panobianco et al., 1999), which might provide different seed soaking velocities, depending on the seed lot.

Concerning the soybean seedling emergence in the laboratory, under different water stress conditions (Figure 1), the best results were obtained for the -0.20 and -0.40 MPa matric potentials. The worst results were obtained when lower and higher water stress treatments were applied (-0.03 and -0.60 MPa), probably because of the excessive and deficient level of available water, respectively. Since low values of matric potential (MPa) provide high water availability in the soil or substrate for seed germination and seedling emergence processes, and vice-versa. High Mpa value might induce reduction on the water availability, causing negative effects on seed germination and seedling emergence. Under excess water (-0.03 MPa matric potencial level), seed lots 17 and 22 presented the worst and best performances, respectively (data not shown). Under water availability levels correspondent to -0.20, -0.40 and -0.60 MPa, lot 2 and lot 18 were superior and inferior as to their seed performance, respectively, which is directly related to the physiological quality of both seed lots. Lot 2 was superior to lot 18 in both characteristics, germination and vigor (Table 1).

A higher physiological quality (germination and vigor) indicates greater probability of having a seed lot with good performance under a wider range of enviromental conditions (Vieira et al., 1994; Egli & TeKrony, 1996; Marcos Filho, 1999), which was confirmed in the present work by the tests of vigor and field emergence. The field evaluation was made using only nine of the initial 22 lots, selected according the performance observed during the first part of the research. The nine seed lots selected and used had contrasting physiological quality.

There was correlation ($P < 0.05$) between EC and field seedling emergence tests (Table 2). The EC test can accurately estimate soybean seedling performance in the field, depending on the overall climatic conditions during the sowing period (Vieira et al., 1999a). It is thus possible to obtain high field soybean seedling emergence when EC values are not greater than 110 μS cm^{-1} g^{-1}, as long as the environmental conditions are adequate. However, if seed germination conditions are not the ideal EC values should not be greater than 90 μS cm^{-1} g^{-1}.

In the case of seedling emergence in the laboratory (Table 2), a relationship was found between the two tests under -0.03 and -0.20 MPa matric potentials ($P < 0.01$), as well as under -0.40 MPa ($P < 0.05$). However, no relationship was observed between tests when -0.60 MPa matric potential was used (higher water stress condition), indicating that the relationship between EC and seedling emergence is highly dependent on environ-

Table 2 - Linear correlation coefficients (r) and t test results obtained for the correlation between the electrical conductivity test (CE) and soybean seedling emergence, in the field and in the laboratory (under different water availability levels in the substrate).

Correlation analysis	r	t test
EC x Field seedling emergence	-0.5233	-2.746*
EC x Laboratory seedling emergence (-0.03MPa)	-0.8040	-3.578**
EC x Laboratory seedling emergence (-0.20MPa)	-0.8919	-5.217**
EC x Laboratory seedling emergence (-0.40MPa)	-0.7553	-3.049*
EC x Laboratory seedling emergence (-0.60MPa)	-0.4545	-1.350NS

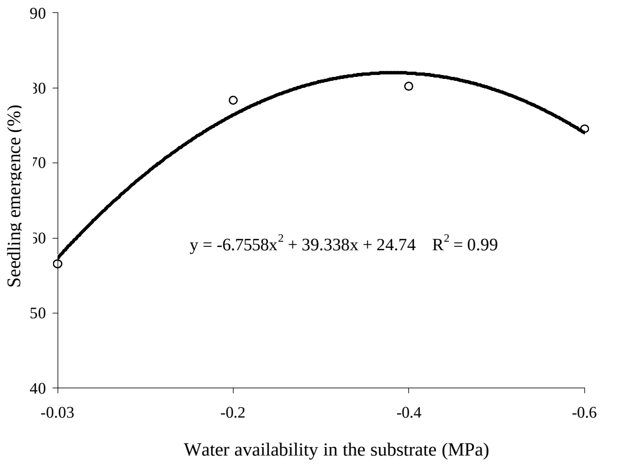

Figure 1 - Soybean seedling emergence in the laboratory, depending on the water availability level in the substrate.

mental conditions. Vigorous seeds have greater probability of superior performance under a wider range of environmental conditions, however, this does not mean these seeds will always present the best field performance, because under marginal environmental conditions (e.g. long period under water stress), even high-vigor seed lots may not guarantee high seed set and adequate plant population in the field. Relationships between EC values and seedling field emergence have been reported under different conditions for a wide range of EC values, up to 110 $\mu S\ cm^{-1}\ g^{-1}$ (Vieira et al., 1999a; 1999b).

The EC results can be used to classify available seed lots and, then, to allow the decision upon the most convenient use of them. For sowing under adequate field conditions, seed lots with up to 110 $\mu S\ cm^{-1}\ g^{-1}$ of EC can be used, and will establish an adequate field stand. However, under a small water stress the use of seed lots with EC > 90 $\mu S\ cm^{-1}\ g^{-1}$ is not recommended.

CONCLUSIONS

A relationship between electrical conductivity of the soybean seed soaking solution and field seedling emergence was found. In the case of seedling emergence in the laboratory, the relationship between EC test values and seedling emergence decreased as the amount of water in the substrate decreased. Relationships between these two variables was also obtained for water availability levels corresponding to -0.03; -0.20 and -0.40 MPa matric potentials. Soybean seed lots presenting EC values up to 110 $\mu S\ cm^{-1}\ g^{-1}$ can be considered high performance seed lots, as long as submitted to adequate field environmental conditions. Otherwise, when a seed lot is exposed to any small water restriction, the critical limit for EC is 90 $\mu S\ cm^{-1}\ g^{-1}$.

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