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EFFECT OF pH LEVELS ON SOYBEAN SEED GERMINATION DYNAMICS

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ABSTRACT

Background. Soybean is a legume of substantial economic importance. The quality and quantity of soybean yield are influenced by various factors include pH soil. Many species of plants have strictly specified physiological requirements concerning the soil pH mainly in early phases of plant development, i.e. seed germination. Traditional methods used in germination data analysis include geramination energy and germination capacity. An alternative may be use tuse of growth models to describe germination process. Mathematical models give considerable information resulting in parameter estimates with relevant biological interpretations.
Material and methods. Soybean seeds (cv. Abelina, Merlin and SG Anser) collected from cultivated plants grown in experimental fields in 2017 and 2018 were analysed. Field experiment was conducted in Łączka, eastern Poland (52°15′ N; 21°95′ E). After harvest, samples of seeds were collected and analysed in the laboratory, seed germination parameters were determined at different pH values of the water solution (pH = 5.0, 5.5, 6.0, 6.5, 7.0). The numbers of germinated seeds were recorded during the period of 14 days. Logistic function was used to analyse cumulative germination curves over time. The function parameters: value of the horizontal asymptote coefficients and rate of increase in germination rate, were calculated.
Results. Generally, the seed germination was the better in 2017 than 2018. The numbers of seeds germinating in 2017 had the highest theoretical asymptotic value (parameter a) and low values of coefficients k (germination rate parameter) and b (shape parameter). Differences were found also between seeds germinated at different pH levels. The pH values of 6 and 6.5 provided were associated with the most rapid germination of all the test cultivars. Based on the logistic function, the highest number of germinated seeds was recorded between day 4 and 6 (germination rate ranging from 18 to 21% per 24 hours).
Conclusion. Testing of germination of cultivars at different pH levels of the medium might be of help while identifying and selecting genotypes for particular locations.

Key words: germination rate, logistic function, pH, soybean (*Glicine* max (L.) Merrill)

INTRODUCTION

Soybean (*Glicine* max (L.) Merrill) is one of the most important leguminous crops cultivated all over the world and used for consumption and feed production purposes (Jarecki and Bobrecka-Jamro, 2015; Balboa *et al*., 2018; Ciampitti and Salvagiotti, 2018). The soybean seed nutritive value is related to the crop's high protein quantity, oil, fatty acids, minerals and B-group vitamins (Bellaloui *et al*., 2014, 2015; Assefa *et al*., 2018; Mourtizinis *et al*., 2018).

The quality and quantity of soybean yield are influenced by habitat conditions, genetic factors as well as the agrotechnology used (Jarecki and Borecka-

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Jamro, 2015). Similarly to other leguminous crop plants, soybean is susceptible to soil acidity and is demanding in terms of soil pH (Alghamdi, 2004; Arslanoglu and Aytac, 2010; Uguru *et al*., 2012; Endrani *et al*., 2021). A number of plant species need acid pH to grow and develop properly. Also, there are species which do not tolerate soil acidity due to the fact that the presence of H+ ions often negatively influences plant development (Budagovskaya, 1995; Deska *et al*., 2011).

Germination, one of seed characteristics which ultimately affects the yield, is very responsive to environmental conditions. The stage of plant germination is the crucial period which substantially impacts crop quality and yield. Seed germination, a complicated biological process, begins with the seed taking up water, and culminates when the embryo emerges from the seed coat hypocotyl (Shafii *et al*., 1991). Germination influences both the growth and development of plants. The time when a seed germinates is a decisive factor of the plant's successful competition with neighbouring plants, its exposition to pests, and correct maturation at the end of the growing season (Kocira, 2018). Due to these considerations, research addressing seeds germination is being undertaken all the time. Germination time and rate are important aspects that can be measured to reflect the dynamics of this process. These traits are of importance to both physiologists/seed technologists and agricultural professionals (Ranal et de Santana, 2006). The process of germination can be described by mathematical functions so scientists very frequently make use of mathematical modelling.

A number of mathematical models have been developed in order to reflect the germination process (Berry *et al*., 1988, Gładyszewska *et al*., 2001; Berry *et al*., 2006; El-Kassabay *et al*., 2008; Muszyński *et al*., 2015; Lamichhane, 2020). The following growth functions are often used while analysing seed germination: logistic function, Gompertz function and Richards function (Tsoularis, 2001; Tsoularis and Wallace, 2002; Karadavut *et al*., 2008; 2009). The growth curves reflect the relationship between seed germination and time, and enable inclusion of many measurements into one equation which is based on several parameters.

The present work aimed at examining, using a logistic function, of the germination capacity of three soybean cultivars grown at different pH levels.

MATERIAL AND METHODS

A two-year (2017–2018) experiment was established at Łączka (52°15′ N; 21°95′ E) to test three non-GMO soybean cultivars, that is check the influence of subsoil pH on their germination. The soil of the experimental site was classified as representing the Haplic Luvisol group according to the World Reference Base for Soil Resources (2014). The soil had average organic carbon and total nitrogen contents as well as average phosphorus content high potassium content and low magnesium content, all in terms of plant available forms (Table 1).

The precipitation and thermal conditions during the study period are presented in Fig. 1.

Table 1. Some soil properties in 2017 and 2018

Year	pH in KCl	C_{org} $g \cdot kg^{-1}$	N_t $g \cdot kg^{-1}$	Fe_t $g \cdot kg^{-1}$	B_t $g \cdot kg^{-1}$	P_{av} $mg \cdot kg^{-1}$	K_{av} $mg \cdot kg^{-1}$	Mg_{av} $mg \cdot kg^{-1}$
2017	7.0	9.5	0.77	998	0.71	55.5	132.7	26.3
2018	7.1	9.1	0.75	995	0.65	57.0	130.5	26.1

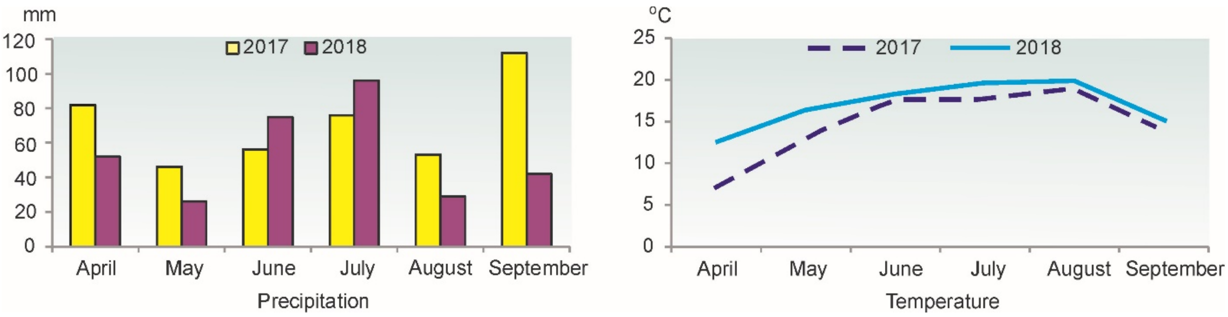

Fig. 1. Precipitation and air temperatures in 2017–2018

In both the study years, August turned out to be the warmest month of soybean growing season with respective average temperatures of 19.0 and 19.9°C. The highest precipitation sum was recorded in September (112 mm) 2017, and July (96 mm) 2018. In contrast, the lowest precipitation sums in 2017 and 2018 were recorded in May and August, respectively 46 and 26 mm, and 53 and 29 mm.

Next the seeds soybean cultivars in the laboratory was carry out the experiment the germination in different water solution pH values. Experiment was a two-way arrangement with three replicates The following factors were investigated: factor A − soybean cultivars (Abelina, SG Anser, Merlin); factor B − subsoil pH (pH = 5.0, 5.5, 6.0, 6.5, 7.0).

After harvest, samples of seeds were collected and analysed in the laboratory. The seeds were disinfected in C_2H_5OH for 24 hours and in 3% $HClO_4$ solution for 8 hours. Next, 50 seeds were placed on each Petri dish, on three layers of damp cellulose filter paper, and the contents of each dish were kept moist at the analysed pH levels and at 20°C during the whole experiment. The numbers of germinated seeds were recorded during the period of 14 days. Next, the counts were used to mathematically describe the germination process of soybean cultivars as affected by the subsoil pH.

The following logistic function was applied to obtain a mathematical description of the number of germinated seeds:

$$y(t) = a/(1+b \cdot Exp(-kt))$$

where:

y(t) − the percentage of germinated seeds,

a − value of the horizontal asymptote (estimated value),

b, k – constant, coefficients of germination (estimated values);

k – germination rate parameter,

b – shape parameter.

The obtained models of seed germination rate as well as function, and inflection points were computed following the equations germination rate (Gregorczyk 1991):

$$\frac{dy}{dt} = \frac{k}{a} \cdot y(t) \cdot (a - y(t))$$

coordinates of the function's inflection point:

$$t_i = \frac{\ln b}{k}, \quad y(t_i) = 0{,}5 \cdot a$$

Statistica 13.0 PL as well as Excel were used to perform the above mentioned calculations).

RESULTS AND DISCUSION

A high germination rate is vital for soybean production as it directly influences the yield (Singh *et al.*, 2010). Although there exists research on germination and initial increase in the number of seedlings of various plants, there is a paucity of works on the impact on pH germination. Deska *et al.* (2012) described the effect of the growing medium pH on the germination and initial development stage of some monocotyledonous and dicotyledonous crop plant species widely chosen to obtain mixtures for green forage production. In turn, Bukvic *et al*. (2007a) did research on the effect of different pH values on the sprouting of leguminous plants.

In the work reported here, differences in parameters due to subsoil pH values were obtained. The seeds of all the cultivars collected in both the study years (2017 and 2018) displayed a similar germination response to different pH levels. Bukvic *et al*. (2007a) reported similar significant differences in seed germination and seedling growth of leguminous genotypes corresponding to different water solution pH values. Also, Bukvic *et al.* (2007b, c) mentioned differences in the seed germination of white clover and alfalfa genotypes resulting from different water solution pH values.

Generally, seed germination was superior in 2017 compared with 2018. This finding is also confirmed by function parameters describing germination rate equations (Tables 2–3).

Table 2. Parameters describing soybean seed germination in 2017 obtained based on the logistic model

Cultivar	pH	Function	t_I day	$Y(t_I)$ %	dy/dt %·day^{-1}
Abelina	5.0	$Y(t) = 84.50[1+98.19\cdot Exp(-0.86t)]^{-1}$	5.33	42.25	18.17
	5.5	$Y(t) = 87.22[1+57.06\cdot Exp(-0.85t)]^{-1}$	4.76	43.61	18.51
	6.0	$Y(t) = 89.68[1+73.40Exp(-1.01t)]^{-1}$	4.25	44.84	22.66
	6.5	$Y(t) = 89.29[1+64.95Exp(-0.93t)]^{-1}$	4.47	44.65	20.82
	7.0	$Y(t) = 86.95[1+57.61Exp(-0.86t)]^{-1}$	4.71	43.47	18.69
Merlin	5.0	$Y(t) = 77.07[1+68.0Exp(-0.83t)]^{-1}$	5.08	38.54	15.99
	5.5	$Y(t) = 77.85[1+62.5\cdot Exp(-0.83t)]^{-1}$	4.93	38.93	16.33
	6.0	$Y(t) = 87.68[1+106.18\cdot Exp(-1.05t)]^{-1}$	4.42	43.84	23.16
	6.5	$Y(t) = 89.83[1+48.6Exp(-0.90t)]^{-1}$	4.32	44.92	20.21
	7.0	$Y(t) = 87.40[1+52.10Exp(-0.81t)]^{-1}$	4.88	43.69	17.69
SG Anser	5.0	$Y(t) = 82.13[1+26.4Exp(-0.61t)]^{-1}$	5.30	41.07	12.68
	5.5	$Y(t) = 88.96[1+22.10Exp(-0.62)]^{-1}$	4.99	44.48	13.79
	6.0	$Y(t) = 89.82[1+71.29Exp(-0.87t)]^{-1}$	4.90	44.91	19.57
	6.5	$Y(t) = 89.84[1+60.40Exp(-0.83t)]^{-1}$	4.91	44.92	18.76
	7.0	$Y(t) = 83.56[1+31.83Exp(-0.64t)]^{-1}$	5.36	41.78	13.49

t_i – inflection point (time-day max. geramination)
$Y(t_i)$ – % of germinating seeds in time t_i
dy/dt – germination rate

Table 3. Parameters describing soybean seed germination in 2018 obtained based on the logistic model

Cultivar	pH	Function	t_I day	$Y(t_I)$ %	dy/dt %·day^{-1}
Abelina	5.0	Y(t) = 83.35 [1+131.20·Exp(-0.91t)]$^{-1}$	5.36	41.67	18.96
	5.5	Y(t) = 80.47[1+80.33·Exp(-0.82t)]$^{-1}$	5.35	40.24	16.49
	6.0	Y(t) = 85.04[1+81.88Exp(-1.05t)]$^{-1}$	4.19	42.52	22.33
	6.5	Y(t) = 85.23[1+61.86Exp(-0.93t)]$^{-1}$	4.42	42.61	19.87
	7.0	Y(t) = 86.67[1+90.78Exp(-0.96t)]$^{-1}$	4.69	43.34	20.83
Merlin	5.0	Y(t) = 88.33[1+48.6Exp(-0.72t)]$^{-1}$	5.39	44.17	15.90
	5.5	Y(t) = 83.29[1+227.3·Exp(-0.95t)]$^{-1}$	5.69	41.65	19.87
	6.0	Y(t) = 85.79[1+82.6·Exp(-0.98t)]$^{-1}$	4.50	42.90	21.02
	6.5	Y(t) = 93.58 [1+96.8Exp(-0.92t)]$^{-1}$	4.94	46.79	21.64
	7.0	Y(t) = 87.37[1+55.6Exp(-0.72t)]$^{-1}$	5.53	43.69	15.88
SG Anser	5.0	Y(t) = 84.01[1+65.9Exp(-0.75t)]$^{-1}$	5.58	42.01	15.75
	5.5	Y(t) = 86.29[1+100.1Exp(-0.84t)]$^{-1}$	5.48	43.15	18.12
	6.0	Y(t) = 87.34[1+47.54Exp(-0.82t)]$^{-1}$	4.66	43.67	18.10
	6.5	Y(t) = 87.37[1+95.29Exp(-0.94t)]$^{-1}$	4.85	43.69	20.53
	7.0	Y(t) = 88.57[1+66.40Exp(-0.71t)]$^{-1}$	5.91	44.29	15.72

t_i – inflection point (time-day max. geramination)
$Y(t_i)$ – % of germinating seeds in time t_i
dy/dt – germination rate

In 2017, the numbers of germinating seeds had the highest theoretical asymptotic value (parameter a) but low values of coefficients k and b. According to Kocira (2018), environmental conditions determine values of 6.0 and 6.5 were followed by the most rapid germination of cv. Abelina. The function inflection point occurred the earliest (respectively, 4.14 and 4.42 days), and the greatest number of germination. The year 2018 was less conducive to the growth and development of soybean plants as it was characterised by unfavourable precipitation and thermal conditions. Soybean seed germination and vigour were reduced by high temperatures during seed filling in the field. Similarly, findings reported by Egli *et al.* (2005) demonstrated that high temperatures during seed filling, when seeds were not infected with *P. longicolla* or physically injured, reduced soybean seed germination and vigour.

Based on the applied model, it was found that the pH germinated seeds was after 4.25 and 4.15 days, respectively (almost 50%), the average increase per 24 hours being about 22%. The pH values of 5.0 and 5.5 contributed to the slowest germination rate of cv. Abelina. The inflection of its function occurred approximately on the 5th day of the trial, and the average seed germination rate was 17.5% per 24 hours. Similar parameters were obtained for all the test cultivars for the germination model at pH = 7.0. In the study conducted to examine *Pisum sativum* germination carried out by Bukvic *et al*. (2007a), poorer seed germination was observed after pH was lowered to 5.0, it being the highest at pH = 7.0.

The pH values of 6.0 and 6.5 were associated with the most rapid seed germination of cv. Merlin, too. The inflection of its function occurred on the 4th experimental day, the average seed germination rate being 23.16% per 24 hours. For cv. Merlin, the pH levels of 5.0, 5.5 and 7.0 extended to about 5 days the time in which the highest numbers of seeds germinated, and a decline was also observed in the average germination rate. Seed germination of cv. SG Anser followed a similar pattern but the inflection of its function occurred the latest.

In 2018, pH = 6.0 was associated with the most rapid germination of all the cultivars. The inflection point of the function for cv. Abelina, Merlin and SG Anser occurred after 4.19th, 4.5th day and 4.66th day, respectively (Table 3). The number of germinated seeds was then about 43%, the average germination rate being about 20% per 24 hours. The lowest germination rate per 24 hours was observed for cv. SG Anser (18%). Similar effects for grass species at a solution pH range of 6.0 to 8.0 were reported by Pérez-Fernández *et al*. (2006). In their study, the highest seed germination rate did not exceed 43%. Deska *et al*. (2011) pointed to improved grass seed germination mainly at pH = 6.5 and 6.0. The aforementioned research demonstrated that the environment acidity of up to pH = 5.5 increased the number of germinating seeds of *Dactylis glomerata*. However, further lowering of the pH value decreased germination by 20%.

The study discussed in the present work involved three soybean cultivars which showed different germination patterns depending on the level of the medium's acidity. Lack of studies on germination of soybean cultivars as affected by pH makes it impossible to thoroughly assess the obtained study results. However, the results confirmed a negative effect of excessively acid reaction of the environment on soybean seed germination. More analyses including other soybean cultivars and pH levels are needed to obtain more in-depth evaluation. The findings reported here do indicate that caution should be exercised while selecting soybean species, particularly in areas where soils display low pH values.

CONCLUSIONS

Soybean seed germination capacity was affected by cultivar and pH. Superior germination was displayed by cv. Abelina. Furthermore, seeds of all the test cultivars germinated better when grown at a pH value of 6 and 6.5. Based on the logistic function, the highest number of germinated seeds was recorded between day 4 and 6, the average germination rate ranging from 18 to 21% per 24 hours (depending on cultivar and pH level). Testing of germination of cultivars at different pH levels of the medium might be of help while identifying and selecting genotypes for particular locations.

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WPŁYW POZIOMÓW pH NA DYNAMIKĘ KIEŁKOWANIA NASION SOI

Streszczenie

Soja (*Glycine* max (L.) Merr.) jest jedną z najważniejszych roślin strączkowych na świecie. Na jakość i wielkość plonu soi mają wpływ różne czynniki, w tym kiełkowanie i pH gleby. Czas i szybkość kiełkowania to ważne parametry opisujące dynamikę tego procesu. W pracy przeanalizowano kiełkowanie nasion soi (odmiany: Abelina, Merlin i SG Anser) zebranych z roślin uprawianych na polach doświadczalnych w 2017 i 2018 roku. Na podstawie wyników doświadczenia laboratoryjnego oceniono dynamikę kiełkowania nasion w zależności od pH podłoża. Obliczono szybkość i tempo kiełkowania nasion oraz teoretyczną (asymptotyczną) wartość funkcji, wykorzystując w tym celu model logistyczny. Stwierdzono, że szybkość i tempo kiełkowania nasion pochodzących z doświadczenia z 2017 i 2018 roku były odmienne. Generalnie nasiona zebrane w 2017 roku charakteryzowały się większą szybkością i większym tempem kiełkowania niż nasiona zebrane w 2018 roku. Ponadto charakteryzowały się najwyższą teoretyczną wartością asymptotyczną (parametr a) oraz niskimi wartościami współczynników k i b. Odczyn podłoża o pH = 6 i pH = 6,5 warunkował najszybsze kiełkowanie nasion u wszystkich odmian.

Słowa kluczowe: funkcja logistyczna, pH, soja (*Glicine* max (L.) Merrill), szybkość kiełkowania