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Notes on Various Parameters Recording the Speed of Seed Germination

M.A. Al-Mudaris*

1 Introduction

In many experiments concerned with seed treatments the pattern of germination, both in time and extent, is the key consideration. Not just the final germination percentage attained, but also the speed and distribution of this germination are often used to judge the agronomic relevance of treatments. Generally, methods of evaluating seed germination responses may be categorized as analytical or graphical (SCOTT *et al.*, 1984). Germination data have several characteristics distinguishing them from other data frequently collected in plant research. For example, germination is traditionally considered to be a qualitative developmental response of an individual seed that occurs at a point in time, but individuals within a treatment respond at different times (SCOTT *et al.*, 1984). Thus, the final germination percentage alone is unsatisfactory for reporting results for two main reasons: (1) It does not facilitate the comparison of germination data published by two authors, and (2) It does not indicate the rapidity of germination but only its final extent (TIMSON, 1965). Therefore, various parameters for measuring or estimating germination speed have been developed with varying degrees of accuracy (HEYDECKER, 1966; SCOTT *et al.*, 1984).

This paper presents a discussion of some of the more frequently used parameters and a comparison of various germination scenarios and their subsequent parameter-based interpretation.

2 Germination Parameters

Table 1 shows various parameters used to assess germination speed and describes formulae for their calculation. The mean germination time (MGT) (ORCHARD, 1977) represents the mean time a seed lot requires to initiate and end germination. The germination index (GI) (BENECH ARNOLD *et al.*, 1991) is a measure of both percentage and speed of germination and assigns maximum arithmetic weight to embryos or seeds that

* Mohamad Abdul Kader (Al-Mudaris), Institute for Crop Science, Kassel University, Steinstrasse 19, D-37213 Witzenhausen, Germany

germinate first and less weight to those that germinate later. For example if all 100 seeds of a lot germinated on the first day of a 10-day trial period, the GI would be 10 ´ 100 = 1000. If all 100 seeds germinated on the tenth day, the resulting GI would be 1 ´ 100 = 100. The coefficient of velocity of germination (CVG) (Jones and Sanders, 1987) gives an indication of the rapidity of germination and increases when the number of germinated seeds increases and the time required for germination decreases. Theoretically, the highest CVG possible is 100. The germination rate index (GRI) (Esechie, 1994) basically gives an indication of the percentage of seeds germinating per day of the test run period. The day on which the first germination event occurs (the first day of germination, or FDG) and the day on which the last germination event occurs (LDG) are also useful in germination speed studies. The time elapsing between the FDG and LDG may, for the purposes of this paper, be termed the time spread of germination (TSG).

3 Germination Scenarios

Three scenarios have been chosen here for the purpose of comparing the effect of germination speed, spread and timing at fixed final germination percentages. Table 2 illustrates a case where 100 seeds of each seed lot were sown into trays and observed for 10 days. The case is a theoretical one assuming an FGP of 80 %. The four lots reflected a contrasting distribution of germination. A number of parameters were used to evaluate seed lot performance including the FGP, MGT, GI, CVG, GRI, FDG, LDG and TSG. Scenarios 2 and 3 are shown in Tables 2 and 3, respectively and focus on the influence of the timing of germination for the majority of the seed lot, and the time spread of this germination, respectively.

4 Distribution of Germination

Although the four lots in Table 2 attained an FGP of 80 %, they did so at varying rates. Lot 1 started germinating on the second day after sowing (DAS) with an equally distributed germination from 2 to 5 DAS. Its MGT was 3.5 days and its GI 600. Seeds of lot 2, on the other hand, completed their 80 % FGP by 1 DAS and, thus, had an MGT of 1.0 day and a GI of 800. Their CVG was 100 compared to the 28.5 of lot 1. Also, their FDG, LDG and TSG were all one because they started and ended germination on the same day. Lot 3 took 3 days to complete germination, with 70 % of its seeds germinating on 2 DAS. This gave arithmetic weight to day 2 and resulted in a MGT of 2.0 days. A somewhat similar case to lot 1 was observed in lot 4 with the 80 % FGP being distributed equally along the TSG period. Here, however, 40 % germinated on 2 DAS and 40 % on 3 DAS, yielding a GI of 680 which is higher than the 600 of lot 1. The CVG was also higher (40 for lot 4 vs. 28.5 for lot 1).

Table 1: Various parameters used to assess the speed of seed germination (for references see text)

Germination Parameter	Symbol	Unit	Formula for Calculation	Description of Formula	Notes
Final Germination Percentage	FGP	%	FGP= Final no. of seeds germinated in a seed lot × 100	-	The higher the FGP value, the greater the germination of a seed population.
Mean Germination Time	MGT	day	$MGT=\sum f\cdot x/\sum f$	f= Seeds germinated on day x	The lower the MGT, the faster a population of seeds has germinated.
First Day of Germination	FDG	day	FDG= Day on which the first germination event occurred	-	Lower FDG values indicate a faster initiation of germination.
Last Day of Germination	LDG	day	LDG= Day on which the last germination event occurred	-	Lower LDG values indicate a faster ending of germination.
Coefficient of Velocity of Germination	CVG	-	$CVG= N_1 + N_2 ... + N_x / 100 \times N_1T_1 + ... + N_xT_x$	N= No. of seeds germinated each day, T= No. of days from seeding corresponding to N	The CVG gives an indication of the rapidity of germination.
Germination Rate Index	GRI	(%/day)	GRI= G1/1 + G2/2 + Gx/x	G1= Germination percentage × 100 at the first day after sowing, G2= Germination percentage × 100 at the second day after sowing	The GRI reflects the percentage of germination on each day of the germination period.
Germination Index	GI	-	GI= (10 × n1) + (9 × n2) +. + (1 × n10)	n1, n2,.., n10= No. of germinated seeds on the first, second and subsequent days until the 10th day; 10, 9,.., and 1 are weights given to the number of germinated seeds on the first, second and subsequent days, respectively	In the GI, maximum weight is given to the seeds germinated on the first day and less to those germinated later on. The lowest weight would be for seeds germinated on the 10th day. Therefore, the GI emphasizes on both the percentage of germination and its speed. A higher GI value denotes a higher percentage and rate of germination.
Time Spread of Germination	TSG	day	TSG= The time in days between the first and last germination events occurring in a seed lot	-	The higher the TSG value, the greater the difference in germination speed between the 'fast' and 'slow' germinating members of a seed lot.

Table 2: Theoretical course of germination of four seed lots with varying times spreads

Day	Lot 1	Lot 2	Lot 3	Lot 4
1	0	80	5	0
2	20	0	70	40
3	20	0	5	40
4	20	0	0	0
5	20	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
Parameter				
FGP (%)	80	80	80	80
MGT (day)	3.5	1.0	2.0	2.5
GI	600	800	720	680
CVG	28.5	100	50	40
GRI (%/day)	25.6	80	41.6	33.3
FDG (day)	2	1	1	2
LDG (day)	5	1	3	3
TSG (day)	4	1	3	2

The GRI in all four lots followed the FGP and MGT. Practically, it would reflect the percentage of seeds germinating per day. Arithmetically, though, it does not always fulfil this. It tends to overestimate the FGP when it is multiplied by the MGT. From Table 2, for example, lot 1 had an FGP of 80 %, an MGT of 3.5 days and a GRI of 25.6 %/day. Theoretically, then, when multiplying the MGT by GRI, the FGP should be 80 %. This is not the case because 3.5 ´ 25.6 = 89.6 %, a 9.6 % overestimate of the actual FGP.

The time when a majority of seeds within a lot germinate seems to be the most influential factor governing the MGT, GI, CVG and GRI, but not the FDG, LDG or TSG. In Table 3 all four lots had an FDG of 2.0 days, an LDG of 5.0 days and a TSG of 4.0 days. Yet because lot 1 had 40 % of its seeds germinate on 2 DAS, the MGT was 2.8 days, the GI 650, the CVG 34.7 and the GRI 31.1 %/day. In lot 2 these 40 % germinated on 5 DAS and so the MGT rose to 4.1 days and the GI, CVG and GRI dropped to 550, 24.2 and 21.3, respectively. Even though 3 DAS witnessed 10 % more germination in lot 3 than in lot 2, the MGT, GI, CVG and GRI were almost similar for both lots reflecting the greater influence of the 40 seeds which germinated on 5 DAS (Table

3). The same applies to the comparison between lots 3 and 4. The third scenario is shown in Table 4. Again, all four lots attained an FGP of 80 %, but both the timing of germination and the TSG varied. In lot 1,

50 % of the seeds germinated on 2 DAS, 20 % on 3 DAS and 10 % on 4 DAS. The MGT, GI, CVG and GRI had values of 2.5 days, 680, 40 and 34.1 %/day, respectively. Although lot 2 had the same LDG as lot 1 its MGT, GI, CVG and GRI values were 3.2 days, 620, 30.7 and 25.0 %/day, respectively. This reflected overall slower germination in spite of the fact that on both germination-event-days, i.e. 3 and 4 DAS, it attained higher FGPs than lot 1. The arithmetic effect of 0 % on 2 DAS in lot 2 compared to 50 % in lot 1, was, however, the decisive factor in the parameter values lot 2 attained. Lot 3 follows the same line of effects where an FGP of 80 % on 4 DAS yielded higher MGT (slower germination) and lower GI, CVG and GRI values than lots 1 and 2. An earlier germination event starting on 2 DAS and ending on 4 DAS with an almost equally distributed FGP on all three germination-event-days was observed in lot 4 and raised germination speed to an even higher level than lot 2. This reflects that both the timing at which the majority of seeds germinate and the TSG govern the resulting speed assessment parameters.

Table 3: Theoretical course of germination of four seed lots with varying timing of seed-majority-germination

Day	Lot 1	Lot 2	Lot 3	Lot 4
1	0	0	0	0
2	40	10	10	40
3	20	10	20	10
4	10	20	10	20
5	10	40	40	10
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
Parameter				
FGP (%)	80	80	80	80
MGT (day)	2.8	4.1	4.0	3.0
GI	650	550	560	640
CVG	34.7	24.2	25	33.3
GRI (%/day)	31.1	21.3	22.1	30.3
FDG (day)	2	2	2	2
LDG (day)	5	5	5	5
TSG (day)	4	4	4	4

Table 4: Theoretical course of germination of four seed lots with varying time spreads and timing of seed-majority-germination

Day	Lot 1	Lot 2	Lot 3	Lot 4
1	0	0	0	0
2	50	0	0	27
3	20	60	0	27
4	10	20	80	26
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
Parameter				
FGP (%)	80	80	80	80
MGT (day)	2.5	3.2	4.0	2.9
GI	680	620	560	641
CVG	40	30.7	25	33.4
GRI (%/day)	34.1	25.0	20	28.7
FDG (day)	2	3	4	3
LDG (day)	4	4	4	4
TSG (day)	3	2	1	3

5 Discussion and Conclusions

From the data of Tables 2, 3 and 4 it appears that one single parameter is in itself not sufficient to fully describe germination. The FGP is an end phase parameter which only reflects the capacity of a seed lot to reach germination. Since it does not reflect either speed, synchrony or spread of germination -all vital factors from horticultural and agronomic standpoints- it should be accompanied by a measure of germination velocity. The MGT tends to be used on a regular basis in seed germination studies and we find no serious setbacks in this except that it lacks the linkage between germination percentage and speed. It also fails to define the TSG or LDG. If accompanied by the GI, the three parameters should facilitate a better interpretation of results. We tend not to favour the use of the GRI in this context since it overestimates the FGP in some, but not all, situations (see Tables 2, 3 and 4 for comparison of the actual FGP with that resulting from multiplying the GRI by the MGT under high and medium GI values). The CVG is merely the reciprocal of the MGT and as such is not an essential parameter to report if the FGP, MGT and GI are presented.

It is also concluded that the MGT, GI, CVG and GRI give maximum weight to the time when the majority of seeds in a lot germinate. This is of major importance for estimating the timing of cultural practices following sowing but does not give the specific TSG. This might have an effect on the synchrony and evenness of germination and resulting seedling stands, respectively.

Timson (1965) proposed the use of an index to give the majority of seeds a greater effect on the magnitude of parameters. The percentage germination is recorded every 24 hours. At the end of some suitable time (10 days as a general guideline) the results are summed. For example if a seed lot attained germination percentages of 40, 20, 0, 0 and 0 on days 1, 2, 3, 4 and 5, respectively, then Timson's Index ($\sum_4$ in this case) would be 40 + 60 + 60 + 60 = 220. But a setback to this method has been reported (Heydecker, 1966), where different germination percentages could still attain the same index, thus complicating interpretation. If the lot above, for example, were compared with a second lot giving germination percentages of 10, 30, 30, 30 and 0 on days 1, 2, 3, 4 and 5, respectively, then the Index would be 10 + 40 + 70 + 100 = 220 which is the same as that of the first lot although the two samples are dissimilar in both germination percentage and the time to ultimate germination. Therefore, we recommend that the FGP be used in conjunction with the MGT and GI as a means of at least representing the germination percentage and its speed both separately and combined.

6 Summary

The final germination percentage alone does not reflect the speed or pattern of germination. Various parameters measuring the speed of germination are evaluated in this paper under three germination scenarios. The final germination percentage should be used together with the mean germination time and the germination index to reflect the percentage and speed of germination separately and in combination.

Bemerkungen zu verschiedenen Parametern der Erfassung der Keimgeschwindigkeit

Zusammenfassung

Die Keimgeschwindigkeit kann nicht durch den endgültigen Keimungsprozentsatz dargestellt werden. Verschiedene Parameter, die die Geschwindigkeit der Keimung messen wurden hier unter drei Keimungsscenarien beurteilt. Die Ergebnisse zeigen, dass der endgültige Keimungsprozentsatz zusammen mit der mittleren Keimungszeit und dem Keimungsindex präsentiert werden soll, um eine vernünftige Darstellung der Keimung und der Keimungsgeschwindigkeit zu erreichen.

7 References

1 BENECH ARNOLD, R., FENNER, M. AND EDWARDS, P., 1991, Changes in germinability, ABA content and ABA embryonic sensitivity in developing seeds of *Sorghum bicolor* (L.) Moench induced by water stress during grain filling. New Phytologist 118, 339-347.

2 ESECHIE, H., 1994, Interaction of salinity and temperature on the germination of sorghum. Journal of Agronomy and Crop Science 172, 194-199.

3 JONES, K. AND SANDERS, D., 1987, The influence of soaking pepper seed in water or potassium salt solutions on germination at three temperatures. Journal of Seed Technology 11, 97-102.

4 ORCHARD, T., 1977, Estimating the parameters of plant seedling emergence. Seed Science and Technology 5, 61-69.

5 SCOTT, S., JONES, R. AND WILLIAMS, W., 1984, Review of data analysis methods for seed germination. Crop Science 24, 1192-1199.

6 TIMSON, J., 1965, New method of recording germination data. Nature 207, 216-217.

7 HEYDECKER, W., 1966, Clarity in recording germination data. Nature 210, 753-754.