Germination characteristics of the grass weed *Digitaria nuda* (Schumach.)

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Abstract

The effect of various pre-treatments and their interaction with temperature on cumulative percentage and the rate of germination were evaluated for *Digitaria nuda*. Stored and fresh seeds were pre-treated with either 0.02 M KNO_3, soaked in water for 24 h (priming), sterilized with 0.5% NaOCl or heat treated at 60 °C. Seeds were germinated at constant temperatures of 25 and 30 °C and fluctuating temperature regimes of 25/10 and 30/15 °C. The effect of pre-chilling on germination of stored and fresh seed was evaluated at 30/15 °C, and seed emergence in two soil types at different burial depths (0, 0.5, 1, 2, 3, 4, 5 and 6 cm) was also determined. The pre-treatment of stored seed with KNO_3 resulted in the highest germination percentage (100%), whereas the pre-treatment of fresh seed with water for 24 h gave the best germination (99%), at constant temperatures of 25 and 30 °C. Pre-chilling of seed increased germination by more than 30%. Emergence from clay loam soil was greater compared with emergence from sandy loam soil. Total seedling emergence decreased exponentially with increasing burial depths with only 5% of seed germinating from a burial depth of 6 cm. Results from this study showed that germination requirements are species specific and knowledge of factors influencing germination and emergence of grass weed seed can assist in predicting flushes in emergence allowing producers to implement control practices more effectively.

Keywords: burial depth; germination; potassium nitrate; priming; soil type; temperature

1. Introduction

Digitaria nuda (Schumach.), commonly known as naked crabgrass, is a relatively unknown *Digitaria* grass species in South African cropping systems. It has recently been positively identified in maize fields in the Free State and North-West Provinces of South Africa. Although *D. nuda* is listed as a weed occurring in crop fields in South Africa, and other countries to the north in Africa, very little information about the ecology and biology of this *Digitaria* grass species is available to establish its weed status and impact on crops (Botha, 2010; Bromilow, 2010; Garbrandt 1985).

Various taxonomic identification keys (Barkworth et al., 2003; Launert and Pope, 1989; Webster, 1983) have demonstrated the morphological similarities between *D. nuda* and the more common *D. sanguinalis* (L) Scop. (large crabgrass) and *D. ciliaris* (Retz.) Koeler (southern crabgrass). The most distinguishable characteristic with which to identify these *Digitaria* spp. correctly can, however, only be seen on the seed when grasses are physiologically mature, making it extremely difficult to distinguish at the seedling stage. *Digitaria sanguinalis* has a very distinct lower glume on the lower lemma and also has some spicules on the lateral veins of the lower lemma. *Digitaria nuda* has no lower glume on the lower lemma in most cases, and if visible, it is only a slight shrivel of a glume. The lower lemma is also very smooth with no spicules on the lateral veins, hence the common name "naked crabgrass". *Digitaria ciliaris* also has an inferior lower glume on the lower lemma, but the lower lemma is smooth like that of *D. nuda* and the upper lemma is longer. Kok et al. (1984, 1989) made a systematic description of the *Digitaria* section in southern Africa and presented five species; including *D. acuminatissima* (Stapf) and *D. nuda* that were not previously recorded. They found that *D. nuda* only occurred in the north-eastern regions of KwaZulu-Natal and Mpumalanga since it prefers more tropical environments, but it was suggested that this species could be more wide-spread due to incorrect identification.

Research on the weed status of *Digitaria* spp. was mostly done on large crabgrass in South Africa (Wells et al., 1980). In field germination studies *D. sanguinalis* is one of few weeds that can germinate throughout the summer growing season with a germination peak two weeks later than most of the common weeds found in maize fields (Du Toit and Le Court De Billot, 1991). Competition of grass infestations, which were dominated by large crabgrass and African goosegrass (*Eleusine coracana* subsp. Africana (K.-O'Byrne) Hilu & De Wet), reduced maize yield up to 70%, and was more severe than *Cyperus esculentus* (L.) (yellow nutsedge) infestations (Jooste and Van Biljon, 1980). *Digitaria sanguinalis* is, however, known to develop high infestations and cause severe competition problems in various crops world-wide (Aguyoh and Masiunas, 2003; Forcella et al., 1992; Fu and Ashley, 2006; Kim et al., 2002; King and Oliver, 1994; Monks and Schultheis, 1998). *Digitaria nuda* has been identified as a troublesome weed in West African countries and Brazil, especially in sugarcane production (Chikoye et al., 2000; Dias et al., 2005). Prior research on *D. nuda* is limited to its taxonomy while its biology and germination ecology are unknown and cannot be inferred from research on other *Digitaria* spp.

Specific requirements for effective germination often differ amongst related weed species and a slight variation in environmental conditions can increase or decrease the rate of their emergence (Hartzler, 1999). Knowledge on the biology and germination characteristics of weeds can be an important tool when implementing integrated weed control strategies, and can be used to prevent significant numbers of new weed seeds being added to the soil seed bank (Chauhan and Johnson, 2009; Hartzler, 1999). Initial germination and the consistency of emergence of a species can support

the decision making process for producers for optimal timing of tillage and herbicide applications. Temperature and soil water content are two of the most important factors influencing germination and emergence of weed species (Chauhan et al., 2006; Ghorbani et al., 1999). The germination characteristics of *D. sanguinalis* and *D. cilliaris* have been extensively studied (Chauhan and Johnson, 2008a, 2008b; Gardener, 1996, Halvorson and Guertin, 2003), but no such studies exist for *D. nuda*.

Preliminary germination tests on *D. nuda* showed very poor germination (<20%) and seed dormancy is expected to be the main reason. Most grass species exhibit some form of dormancy where low germination percentages are experienced despite prevailing favourable conditions. Several treatments that promote or enhance germination can be used to break physiological dormancy and have been used to do so in *D. sanguinalis* and *D. ciliaris* (Chauhan and Johnson, 2008a, 2008b; Gallart et al., 2008; Moreno and McCarty, 1994).

The objectives of this study were to determine germination characteristics of *D. nuda* utilising various pre-treatments aimed at breaking dormancy and increasing seed germination using constant and fluctuating temperature regimes in order to identify optimal germination conditions for each of the pre-treatments. Knowing the optimum temperature range in which a specific weed species germinates could shed light on the biology of such a species and can be useful in predicting significant flushes of emergence, leading to more pro-active and practicable control measures. Furthermore, the influence of soil type and seed depth below the soil surface was also investigated to determine effects on seedling emergence.

2. Materials and methods

2.1. Seed collection

Digitaria nuda seed was collected annually from physiologically mature plants during March and April from 2007 to 2011 at the research station of the ARC-Grain Crops Institute, Potchefstroom (North-West Province, 26°43'41.9" S, 27°04'47.8" E). Since *D. nuda* is a relatively unknown grass species in South Africa, at least with regard to its distribution, racemes sampled in each year were sent to the National Herbarium of the South African National Biodiversity Institute to be positively identified. After collection, seed was left to dry in a glasshouse at 30/15 °C (day/night) temperature range for two weeks. Seed was removed from racemes by hand and cleaned from inert material to obtain experimental samples. Samples of each year were kept separate and stored in air-tight plastic containers at 15 °C. Seed properties are summarized in Table 1.

Table 1. Seed properties of *D. nuda* collected in Potchefstroom from 2007 to 2011.

Seed year collected	Seed mass (g.100⁻¹)	Pure seeds[a]	Caryopsis present[b]	Viable seed[c]
			%	
2007	0.189	94	43	28
2008	0.199	98	59	50
2009	0.188	91	31	14
2010	0.248	96	57	58
2011	0.292	94	78	49

[a] seeds of *D. nuda* per sample; [b] intact, germinable seeds; [c] viable seeds determined with tetrazolium tests.

2.2. Germination tests

Germination tests were done using both 1-year old seed (harvested in 2010) and fresh seed (harvested in 2011) of *D. nuda* to compare germination. Seed harvested during 2010 was stored in air-tight plastic containers at 15 °C following drying until commencement of germination tests in 2011. Five different seed pre-treatments to enhance germination of *D. nuda* were applied to both stored (1-yr old) and fresh seed: 1) KNO_3 applied at 0.02 M in place of distilled water, 2) immersing (priming) seed for 24 h in distilled water (water 24 h), 3) sterilization in 0.5% NaOCl solution for 10 minutes followed by rinsing with distilled water, 4) heat treatment of seed in brown paper bags at 60 °C for 24 h (heat treatment), and 5) control treatment where seed was not pre-treated.

One hundred seeds of *D. nuda* were placed separately in polyethylene containers (22 x 15 x 5.5 cm) on brown Anchor germination paper (once folded) for each treatment, which was replicated four times (total of 400 seeds per treatment). Distilled water (13 ml) was added to the germination paper to provide moisture, except where KNO_3 was used. Since temperature can play a major role in the germination of grass seed, all germination treatments were repeated at constant temperatures of 25 and 30 °C, and fluctuating temperature regimes of 25/10 and 30/15 °C using growth chambers with day/night (14 h light/10 h dark) conditions. These temperatures and day/night light regimens were chosen to reflect temperature and diurnal variation in maize- producing areas in South Africa where *D. nuda* and *D. sanguinalis* commonly occur as troublesome weeds in maize fields (Table 2). Germinated seeds were counted and removed when a white protrusion of the radicle was observed. The duration of each trial was 30 days.

Table 2. Average 10-year maximum and minimum temperatures for four South African localities where severe *D. nuda* infestations had been reported.

Locality	Potchefstroom		Viljoenskroon		Bothaville		Wesselsbron	
GPS co-ordinates	27°04'31.91'' S		26°54'32.29" S		26°40'55.88" S		26°26'30.69" S	
	26°43'50.18" E		27°10'45.05" E		27°18'12.31" E		27°41'27.85" E	
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
	°C							
Early[a]	28.80	13.46	29.86	11.56	30.28	9.62	29.79	11.92
Mid	29.05	16.51	30.72	15.6	30.15	15.2	31.03	15.76
Late	29.08	15.02	29.01	13.86	28.29	13.8	28.94	14.19

[a]Crop growth season was divided into early season (Oct to Nov), mid-season (Dec to Jan) and late season (Feb-March).

2.3. Effect of pre-chilling

Minimum temperatures during winter months in areas where *D. nuda* occur fluctuate between 0 and 10 °C, with frost occurring regularly. *Digitaria nuda* seed from stored (1-yr old) and fresh samples was pre-chilled for three months at 4 °C after which germination tests were carried out as described above. Germination tests were, however, only done at the fluctuating temperature regime of 30/15 °C (14 h light/10 h dark) in a growth chamber, thus simulating seasonal temperature fluctuations.

2.4. Data analysis of germination trials

A split-plot factorial analysis was done on data with temperatures (4 factors) as whole plots, and treatments and seed age (5 X 2 factors) as sub-plots. The means of significant interaction effects were compared using Fisher's Protected t-LSD at a 5% significant level using GenStat for Windows 15th edition (Payne 2011). Mean germination time (MGT) was determined for all treatments, temperature regimes and seed age. Cumulative germination was normalized in each treatment, setting the maximum germination at 100% (King and Oliver, 1994). A germination index was determined to compare germination rates between treatments and temperatures using the equation described by Maguire (1962):

$$GI = \Sigma n_i/t_i \qquad [1]$$

where n_i is the percentage seeds germinated at the ith day and t_i is the number of days recorded from the onset of the experiment to the last day on which seeds germinated. The Mitscherlich curve was fitted on cumulative germination to determine time to 50% of final germination (Brown and Mayer, 1988; Ismail et al., 2002):

$$Y = M[1-\exp(-K(t-L)] \quad [2]$$

where Y = cumulative germination at time t, M = asymptote (theoretical maximum for Y), L = the time (day) seed started to germinate, K = rate of increase in germination.

2.5. Effect of burial depth

The effect of different burial depths on the emergence of *D. nuda* seedlings was studied in two soil types in a glasshouse at a temperature regime of 30/15 °C (day/night), which simulated the expected average regime in the respective maize production areas (Table 2). Tetrazolium tests (ISTA, 2010) were done on stored, non-germinated seeds collected in 2007, 2008, 2009 and 2010 to determine the percentage viable (fresh) and non-viable (dead) seed for each seed year. Soil was collected from each of two experimental farms of the Agricultural Research Council namely ARC-Grain Crops Institute in Potchefstroom and ARC-Small Grains Institute in Bethlehem (28°09'55.12" S, 28°18'32.97" E). Potchefstroom and Bethlehem soils had a clay content of 36% (Hutton clay loam) and 16% (Avalon sandy loam), respectively. Soils were sterilized separately with methyl bromide, sieved and placed in square polyethylene containers (275 x 275 x 145 mm). Each container was marked in cm to enable planting at specific depths below the soil surface. Soil temperature for each increment was measured; there was less than 1 °C difference between the soil surface and 6 cm depth.

One hundred seeds of each seed year were placed on the soil surface at the respective burial depths of 0, 0.5, 1, 2, 3, 4, 5 and 6 cm and covered with soil. Soil was rolled firmly after seeding at each burial depth to ensure good soil-seed contact. The experiment was a randomized complete block design and each treatment was replicated six times (treatments were replicated three times; whole experiment was repeated for each soil type). Moisture content at field capacity (FC) of the soils was determined gravimetrically by means of weighing of containers prior to and after water was applied in excess and thereafter allowing water to drain freely for 12 hours. The clay loam (Potchefstroom) and sandy loam (Bethlehem) soil was watered daily with 200 and 150 ml, respectively, to maintain soil as close as possible to FC in order to prevent water stress from influencing seedling germination. Chemicult, a commercial liquid fertilizer, diluted with water as specified on the label, was applied to all treatments 14 days after seeding at a fixed volume of 100 ml per container. Holes in the bottom of the containers ensured free drainage of water. Seedlings were counted after emergence of the coleoptile and development of the first fully unfolded leaf (ligula clearly visible). Mean time to emergence (MTE) was adapted from the mean germination time formula and calculated as follows:

$$MTE = \Sigma(n \text{ X } g)/N \quad [3]$$

where *n* is the number of emerged seedlings on day *g* and *N* is the total number of seedlings emerged.

Total number of plants that emerged from each burial depth was counted daily for 22 days after planting (DAP) when emergence was no longer observed in both soil types. The maximum total of *D. nuda* seedlings that could potentially emerge from each seed year was determined by the sum of the percentage normally germinated seedlings and the percentage viable seed determined from the tetrazolium tests. The trial was terminated 42 DAP when plants were cut at the soil surface. Mean dry mass of leaves and stems was determined for each treatment after drying overnight at 60 °C. Total emergence of seed sampled in 2009 was less than 12%, and viable seed was only 14%, hence, it was decided to omit 2009 data from analyses. Data for seed from 2007, 2008 and 2010 were subjected to ANOVA using GenStat for Windows 15th edition (Payne, 2011). Regression analysis was used to determine the relationships between burial depth, seed year and soil type using an exponential model to describe the relationship:

$$E = A_{max}e^{(-bx)} \quad [4]$$

where E = emergence (%) at seed burial depth *b*, A_{max} = maximum potential plants emerged, and *x* = slope.

3. Results

3.1. Germination tests

Germination patterns of *D. nuda* differed greatly between seed ages, pre-treatments and temperature regimes. Cumulative germination to determine 50% of final germination is shown in Figure 1 only for control, KNO_3 and water 24 h pre-treatments at constant 25 and 30 °C and fluctuating 25/10 and 30/15 °C temperature regimes (model parameters Table 3). The heat pre-treatment failed to reach 50% of final germination at constant and fluctuating temperature regimes. Only stored seed that was sterilized showed germination greater than 50% and these pre-treatments will be discussed under final germination. At 25 °C, stored seed treated with KNO_3 and fresh seed soaked water for 24 h reached 50% of final germination within three days. One year old seed soaked in water and fresh seed in control treatments reached 50% of final germination only after 16 and 18 days, respectively, but failed to reach germination percentages greater than 60%. The same tendency was observed for stored and fresh seed in the KNO_3 and 24 h water treatment at 30 °C, but the control treatments failed to reach 50% of final germination. One year old seed soaked in water for 24 h reached 50% of final germination within 5 days at 30 °C. Seed in control treatments failed to reach 50% of final germination at 30 °C. Both seed ages of *D. nuda* seed failed to reach 50% of final germination in all treatments at the fluctuating 25/10 °C temperature regime. At the 30/15 °C regime stored seed soaked in water for 24 h took six days to reach 50% of final germination, while fresh seed took 19 days. One

year-old seed in control treatments took 14 days and fresh seed treated with KNO$_3$ took 19 days to reach 50% of final germination.

Seed, regardless of age, that started to germinate early (within three to six days) reached final germination percentages of between 80 and 100%. Seed that germinated more slowly over extended periods showed mostly germination of less than 50%. Low and prolonged germination in control treatments and failure to reach 50% of final germination accentuates the difficulty experienced with seed germination of *D. nuda*.
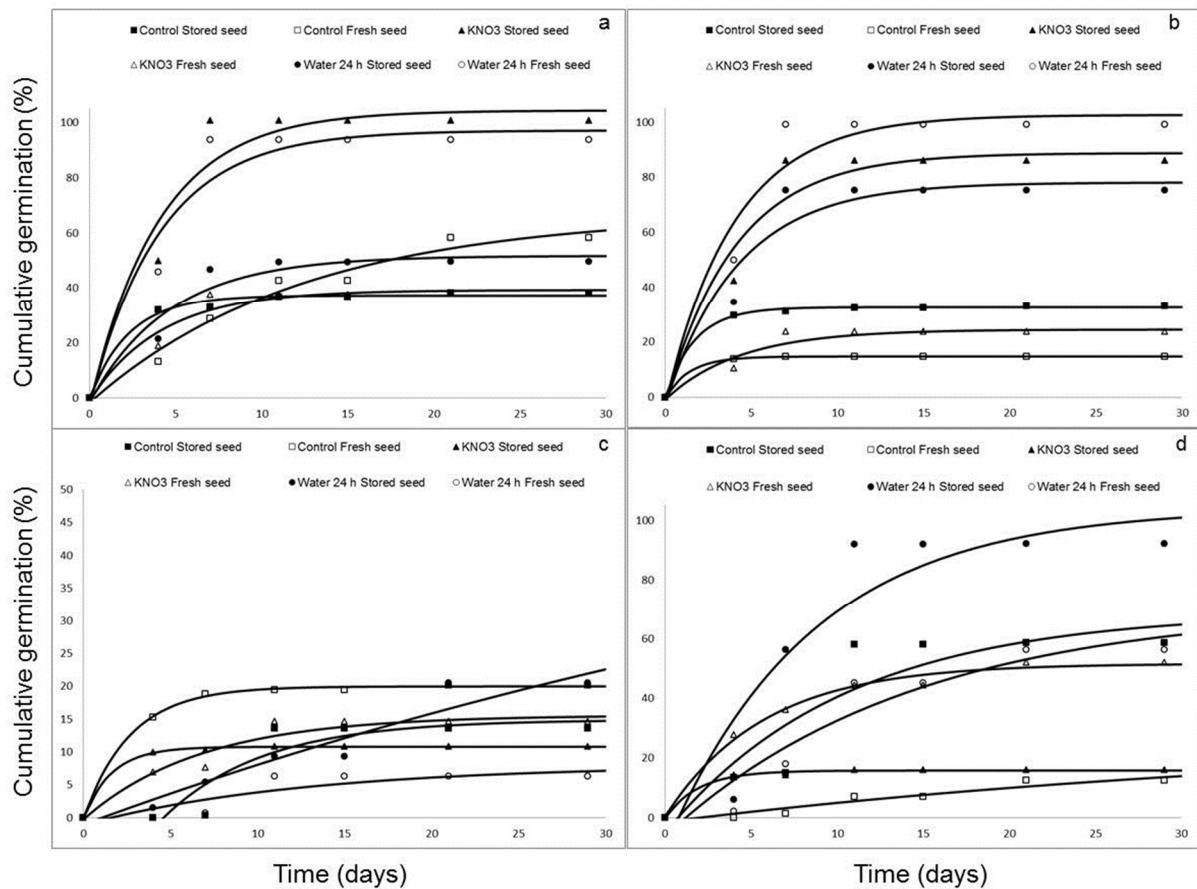

Figure 1. Cumulative germination patterns of stored (1-yr old, solid legends) and fresh (open legends) *D. nuda* seed at constant temperatures regimes of (a) 25 and (b) 30 °C and fluctuating temperatures of (c) 25/10 and (d) 30/15 °C for control, KNO$_3$ and soaking in water for 24 h treatments. (Symbols are the actual data and lines are the predicted values fitted to the Mitscherlich curve Y = M[1 - exp(- K(t - L))], using the values shown in Table 3)

Table 3. Parameter estimates of the logistic function (Mitscherlich curve) fitted to cumulative germination in Figure 1.

Parameter[a]	Temperature regime (°C)					
	25					
	Control	Control	KNO$_3$	KNO$_3$	Water 24 h	Water 24 h
	Stored	Fresh	Stored	Fresh	Stored	Fresh
M	37.239	67.063	104.367	39.26	51.688	97.117
K	0.43232	0.08057	0.24479	0.24012	0.21418	0.24318
L	-0.00614	0.31316	0.09293	0.08986	0.13386	0.09593
	30					
M	32.698	14.83	88.902	24.573	78.225	102.731
K	0.58614	0.69493	0.24393	0.22949	0.23466	0.24779
L	-0.00056	0.00005	0.09453	0.12594	0.11357	0.08765
	10/25					
M	14.88	19.946	10.773	15.557	63.662	7.995
K	0.17343	0.3696	0.61049	0.14732	0.01511	0.07798
L	4.60286	0.00109	-0.00058	0.10328	1.07664	1.59304
	15/30					
M	68.986	28.765	15.782	51.632	104.097	70.871
K	0.09566	0.02369	0.51015	0.17457	0.11887	0.06988
L	0.74363	2.01271	-0.00287	-0.0553	0.78573	1.1946

[a] M = asymptote (theoretical maximum for Y), K = rate of increase in germination, L = the time (day) seed started to germinate.

Although temperature and pre-treatments had the greatest effect on mean germination time (F=143.00, P<0.001; F=28.48, P<0.001, respectively), a significant interaction between temperature, pre-treatments and seed age was recorded (F=8.95, P<0.001). The mean germination time for *D. nuda* was between five and seven days after seeding for most pre-treatments at constant temperatures of 25 and 30 °C, only the control and heat pre-treatment for fresh seed took significantly longer to germinate (13 to 20 days). Germination at fluctuating temperature regimes took twice as long in most pre-treatments with no further germination after 20 days.

Seed age of *D. nuda* had the greatest effect on final germination (F=63.08, P<0.001) followed by temperature (F=46.90, P<0.001) and pre-treatments (F=45.41, P<0.001). All the possible interactions between seed age, temperature and pre-treatments were, however, significant and are shown in Table 4 (F=13.24, P<0.001). The lowest germination for stored and fresh seed was recorded in the fluctuating temperature regime of 25/10 °C and varied between two and 20% over all pre-

treatments. Germination of fresh seed increased by more than 40% when soaked in water for 24 h at constant temperature of 25 °C. In contrast, the opposite pattern was found at the fluctuating temperature regimes of 30/15 °C: germination of stored seed was greater than that of fresh seed. Potassium nitrate increased germination of stored seed by more than 60% at both constant temperatures of 25 and 30 °C. The priming of fresh seed with water showed, however, the best germination (>94%) at both constant temperatures. Sterilized stored seed showed germination of between 57 and 73% at both constant temperatures of 25 and 30 °C and fluctuating temperatures of 30/15 °C. Heat pre-treatment of seed did not enhance germination for either fresh or stored seed.

Table 4. Effect of different temperature regimes and germination treatments on final germination (%) of stored (1-yr old) and fresh *D. nuda* seed.

| | Temperature regimes (°C) | | | | | | | | |
| | 25 | | 30 | | 10/25 | | 15/30 | | |
Treatment	Stored	Fresh	Stored	Fresh	Stored	Fresh	Stored	Fresh	Mean[a]
Control	38.25	56.39	33.13	11.11	13.55	20.14	58.74	12.50	30.48b
KNO$_3$	99.57	38.19	85.85	23.61	10.84	14.58	15.97	29.86	39.81c
Heat treatment	34.94	0	31.33	11.81	9.33	22.92	42.47	24.30	22.14a
Sterilized	64.46	12.50	57.23	38.89	2.41	2.78	72.89	19.45	33.83bc
Water 24 h	49.70	93.75	75.30	99.31	20.48	6.25	92.17	56.25	61.65d
Mean[b]	57.38d	40.17c	56.57d	36.94bc	11.32a	13.33a	56.45d	28.47b	
Mean[c]	48.78b		46.76b		12.33a		42.46b		

LSD$_{(Temperature \times Treatment \times Seed\ age)}$ = 18.02

[a] mean germination for treatments, [b] mean germination for seed age and temperature interaction, [c] mean germination for temperature. (Means within columns or rows followed by the same letter(s) do not differ significantly at P=0.05).

A significant interaction between temperature, pre-treatments and seed age was also recorded for germination rate of *D. nuda*. Results obtained for germination rate were similar to that of final germination where the highest germination rate was recorded for fresh seed soaked in water, followed by stored seed that was sterilized and treated with KNO$_3$, at constant temperatures (data not shown). Therefore, the best germination (100%) for stored *D. nuda* seed can be achieved where seed is germinated in KNO$_3$ at 25 °C, while fresh seed have to be soaked in water for at least 24 h prior to conducting germination tests at 30 °C.

3.2. Effect of pre-chilling

A significant interaction between pre-chilling, pre-treatments and seed age was recorded for all parameters tested (MGT: F=31.25, P<0.001; Germination: F=15.31, P<0.001; GI: F=10.58, P<0.001). Seed that was not pre-chilled germinated within six days only when treated with KNO_3. Pre-chilled fresh and stored seed did, however, germinate faster in all the other pre-treatments and took between seven and nine days to germinate compared to 12 and 22 days where seed was not pre-chilled (data not shown). Although the interaction effect on germination will be discussed, it is worth mentioning that the main effect of pre-chilling increased germination by 33%. Germination of stored seed was significantly greater in pre-chilled seed that was either treated with KNO_3 or pre-treated at 60 °C. Pre-chilling did not improve germination significantly for stored seed in the control, sterilized and soaking in water pre-treatments. Germination was, however, significantly greater in pre-chilled fresh seeds in all pre-treatments, except where seed was pre-treated with heat (Figure 2).
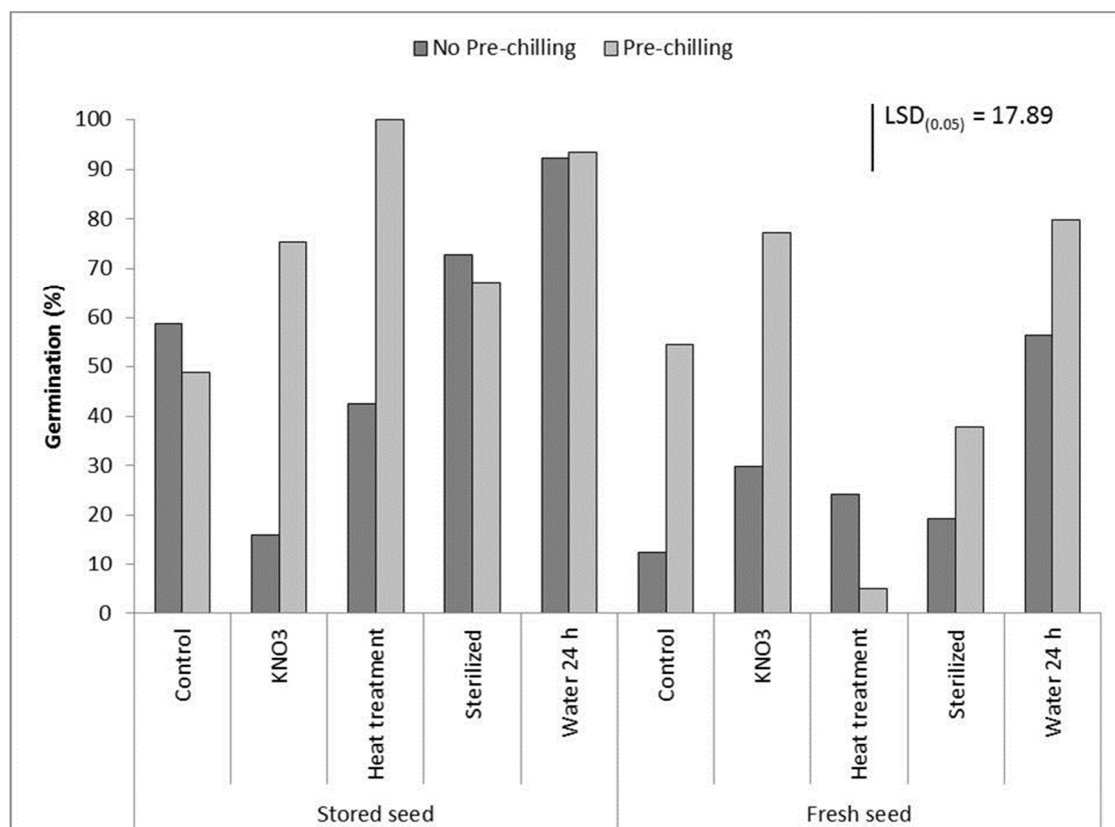

Figure 2. Effect of pre-chilling on the germination of fresh and stored (1-yr old) *D. nuda* seed subjected to various pre-treatments to enhance germination at fluctuating 30/15 °C temperature regime (Significance determined at P=0.05 according to Fisher's $LSD_{(Pre-chilling \, x \, Pre-treatment \, x \, Seed \, age)}$)

3.3. Burial depth

Burial depth was the only main effect that influenced MTE significantly ($F=5.10$, $P<0.001$) and no significant interactions were recorded for this parameter. Seedlings emerged more rapidly when placed on the soil surface and at depths of 0.5 and 1 cm (9 days). Seed buried deeper than 3 cm resulted in slower emergence of up to 15 days after seeding. Only soil type ($F=30.19$, $P<0.001$) and burial depth ($F=15.57$, $P<0.001$) significantly affected dry mass of *D. nuda;* no interactions were significant (soil type, burial depth, seed year). Dry mass harvested from clay loam soil was more than double the mass produced on sandy loam soil (5.0 and 2.3 g, respectively data not shown). Dry mass decreased with an increase in burial depth (Figure 3). The highest dry mass for grass seedlings was recorded for seedlings emerging from seed at a burial depth of up to 2 cm, but 40% reduction in dry mass was recorded where seed was buried deeper than 4 cm.
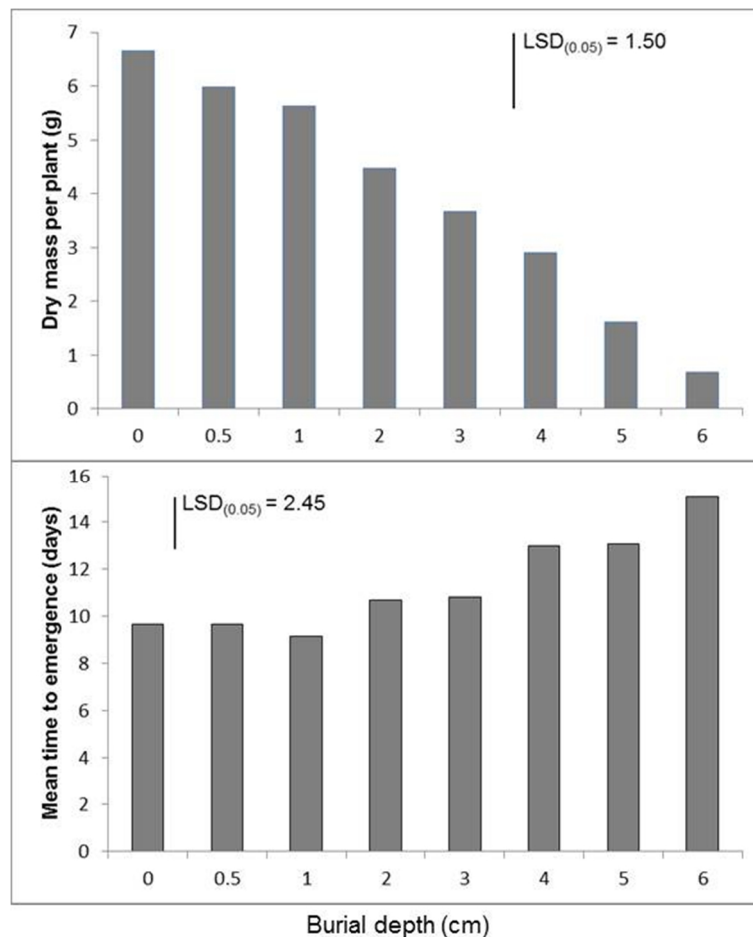

Figure 3. Effect of burial depth on mean time to emergence and dry mass per plant of *D. nuda* seedlings harvested 40 days after seeding (Significance determined at $P=0.05$ according to Fisher's LSD)

Total plants emerged were significantly influenced by soil type, burial depth and seed year, but no significant interaction effects were recorded. *Digitaria nuda* emergence was 20% greater in clay loam compared with sandy loam soil. The lowest total plant emergence was recorded for the oldest seed sample (2007), but no significant difference was observed between seed harvested from 2008 and 2010. Total plant emergence decreased exponentially with increasing burial depth. Emergence was reduced by 27% after burial at 1 cm and by 61% at a burial depth of 3 cm. Only 5% of *D. nuda* seed emerged from a burial depth of 6 cm (Fig. 4).
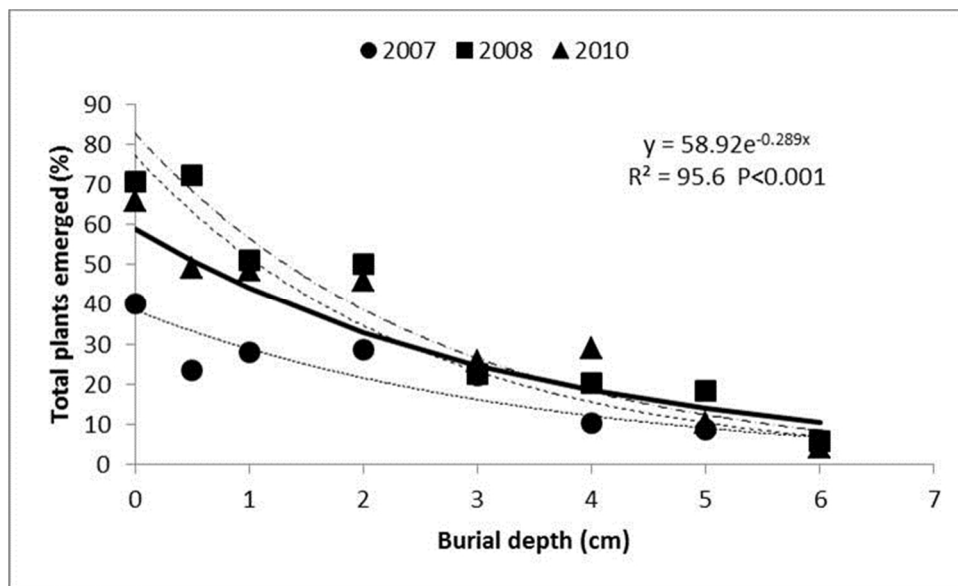

Figure 4. Effect of increasing burial depth on the total plants of *D. nuda* emerged (solid line represent mean and dashed lines indicates relationship for each seed year).

4. Discussion

Digitaria species reproduce mainly by seed, and most seed shows some dormancy after shedding (Gardner, 1996), but can germinate throughout the season in cycles or flushes when favourable conditions prevail during the summer months coinciding with maize production. There is considerable variation in the timing of seed maturation with *Digitaria* spp. and it is difficult to collect large seed samples with uniform maturity. This and the fact that each plant genotype interacts with the environment during maturation could explain in part, the variation in germination reported for *D. nuda* (Taylorson and Brown, 1977). Although initial germination of stored *D. nuda* started at five days, germination was very low (<30%) and most seed still did not germinate 20 days after seeding without any pre-treatment of seed. Storage alone could not break the dormancy that may be present in freshly harvested *D. nuda* seed effectively. Several studies with *D. sanguinalis* have shown that

storage of seed for periods longer than six months can be enough to increase germination significantly (Gardner, 1996; King and Oliver, 1994; Toole and Toole, 1941; Zhang et al., 2012). Gardner (1996) found that fresh *D. sanguinalis* seed took a minimum of 196 days (6.5 months) to germinate while Toole and Toole (1941) reported seven to 14 days for seed stored for one year.

Germination rate and seedling development are greatly dependent on temperature and according to Steinmaus et al. (2000) is the most important factor regulating germination of non-dormant seed. The daily fluctuating temperature regimes experienced in the field at localities where severe *D. nuda* infestation occur were simulated in growth cabinets to compare with constant temperature treatments. The higher fluctuating temperature regime of 30/15 °C increased mean germination of *D. nuda* seed significantly (>70%), but did not differ significantly from the constant temperatures of 25 and 30 °C. Specific pre-treatments in combination with temperature yielded the highest germination for fresh and stored *D. nuda* seed.

Germination of *D. sanguinalis* was found to be optimal at temperatures between 20 and 30 °C and has a base temperature of 16.2 °C (King and Oliver, 1994; Steinmaus et al., 2000). Fluctuating temperatures have been found to be an important stimulus and even may be a requirement for certain annual grass weed species to germinate successfully (Nishimoto and McCarty, 1997). Due to the small seed size (2.0 to 2.8 mm) and light weight (100 seed weight = 0.22 g), most of the seed of *D. nuda* accumulate within five to six centimetres of the soil surface. ISTA Rules (2010) recommend the use of KNO_3 for breaking dormancy of grass seeds. The pre-treatment of *D. nuda* seed with KNO_3 also increased the germination significantly but only in combination with relatively high constant temperatures. KNO_3 increased germination of *D. sanguinalis* where mean germination of 99% was achieved and dormancy induced by caryopsis covering structures and the pericarp was successfully decreased (Gallart et al., 2008). The positive effect of KNO_3 on germination of seed has been linked with an osmotic effect that enhances water and oxygen uptake by the embryo and a nutritional effect on protein synthesis (Gallart et al., 2008). Maize yield can be correlated with the amount of nitrogen available in soil and producers will amend their fertilizer programmes accordingly. Enhancing nitrogen in soil may therefore stimulate germination of *D. nuda* seed when high soil temperatures prevail.

Soaking freshly matured *D. nuda* seed for 24 h in water significantly increased germination especially under constant temperature of greater than 25 °C. Pre-soaking or priming of seed with water over a period of time is not directly involved in breaking dormancy, but has rather an effect on the germination process itself (Biswas et al., 1978; Gallart et al., 2008). Naturally occurring inhibitors could be removed or washed out, initiating the germination process. Biswas et al. (1978) also found that certain enzyme activities that are beneficial for the germination process increased when soaking seed in water. Improved germination of pre-soaked *D. nuda* seed may be due to the removal of

putative inhibitors, the decrease of mechanical constraints, a change in permeability of covering structures or a combination thereof (Baskin and Baskin, 2004; Gallart et al., 2008).

The heat pre-treatment of *D. nuda* seed yielded poor germination for both stored and freshly matured seed, except where stored seed was pre-chilled for 3 months. After-ripening of seed at 50° C for longer than 14 days increased germination of *D. ischaemum* (Schreb.) Muhl. (smooth crabgrass) and *D. sanguinalis* significantly (Taylorson and Brown, 1977). The short exposure of *D. nuda* seed to 60° C (only 24 h) was perhaps not long enough to break existing dormancy and increase germination. Although pre-chilling of *D. nuda* seed increased germination and can possibly break dormancy (Toole and Toole, 1941) the associated mechanisms/processes involved in the germination process was deemed beyond the scope of this study.

Although *D. nuda* seedlings emerged faster from within the first three centimetres of soil and were larger compared with the later emerging seedlings, the effect on seed production was not measured. The effect on plant growth and seed production can also be due to the longer growing period of first emerging plants and better environmental conditions earlier in a growing season. Reproductive traits and seed production of *D. sanguinalis* were significantly influenced by time of emergence where plants emerging first had greater seed production than those emerging later (Gallart et al., 2010).

Digitaria nuda emerged faster and grew better in clay loam soil, but showed very little emergence from a depth of 6 cm below the soil surface. According to Halvorson and Geurtin (2003) *D. sanguinalis* can be found in nearly every soil type but grows better in sandy loam soils than clay soils with no emergence deeper than 6 cm. The decrease in emergence from deeper soil depths is mostly due to limited light, smaller seed size and also the gaseous environment and soil gas permeability (Benvenuti, 2003; Chauhan and Johnson, 2008a, 2008b). Benvenuti (2003) also found that soil physical properties play a major role in annual germination and emergence of weed seeds. Seed emergence was less prominent in sandy soil when compared with clay soil, and they concluded that clay soils showed better pedological conditions to accumulate certain weed seeds in a soil bank. Although significance between soil types was established in our study, severe infestations of *D. nuda* were observed in the previously mentioned maize-producing areas that consisted mostly of sandy soils with low clay content. Although *D. nuda* prefers clay soil, it has the ability to germinate and emerge successfully in sandy to sandy loam soils.

Effective seed germination is a key factor in the establishment of grass weed populations in crop production systems and is regulated by several factors. This study showed germination requirements to differ between related crabgrass species and to be very specific. Determining the effect of different factors influencing the germination ecology of a weed specie, can assist in predicting flushes in emergence, thereby allowing for better timing of control practices. Constant high

temperatures stimulated germination of *D. nuda* as has been reported for *D. sanguinalis* (Moreno and McCarty, 1994). In our study *D. nuda* germinated better than 50% at fluctuating 30/15 °C suggesting that season-long germination is possible especially in most maize producing areas where temperatures range between 15 and 35 °C.

Most studies on grass emergence indicated that more than 70% of seeds will germinate on the soil surface within the first year of seed shedding. Results from this study indicated that emergence of *D. nuda,* as with many other grass weed species, declined with increasing burial depth. This implies that rather shallow soil cultivation would be required, which might even be acceptable in cropping systems where minimum tillage is practiced. Subsequently, timely application of herbicides post-emergence will be necessary to control late emerging seed from existing seed banks or dormant seed from previous seasons.

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