Effect of Ecological Factors on Germination of Horse Purslane (*Trianthema portulacastrum*)[1]

Efeito de Fatores Ecológicos na Germinação de (Trianthema Portulacastrum)

TANVEER. A.[2], MUMTAZ. K.[2], JAVAID, M.M.[3]*, CHAUDHRY, M.N.[4], BALAL, R.M.[5], and KHALIQ, A.[2]

ABSTRACT - *Trianthema portulacastrum* is a very problematic summer crop weed and a complete crop failure has been observed because of this weed at high density. The effect of different ecological factors on germination of *T. portulacastrum* seeds collected in two different years (2009 and 2005) was studied in laboratory experiments. An increase in temperature from 25 to 35 °C increased germination percentage of *T. portulacastrum* from 65 to 85%, after which germination started to decrease, reducing to 71.25% at 45 °C. *Trianthema portulacastrum* had maximum germination with distilled water compared with different salt solutions and drought stress levels. Germination was significantly minimum at salinity and drought stress level of 250 mM and -0.8 MPa, respectively. Emergence of *T. portulacastrum* was maximum (86.25%) at 100% field capacity level but decreased sharply as field capacity decreased thereafter, and minimum emergence (30%) was recorded at field capacity level of 25%. Germination of *T. portulacastrum* was lowest at pH 5 and any increase in pH resulted in increased germination. A pH range of 8 to 10 had statistically similar germination. Sowing depth of 6 cm reduced the emergence of *T. portulacastrum* to zero. Reduction in emergence was recorded with depth increase from zero to 5 cm. Maximum emergence was recorded from soil surface (0 cm). An increase in temperature, salinity, drought, sowing depth (up to 4 cm) and a decrease in field capacity increased time to start germination/emergence, time to 50% germination/emergence and mean germination/emergence time but decreased germination/emergence index. Seeds collected during 2009 gave higher germination than old seeds collected in 2005. This information might contribute to development of effective control of *T. portulacastrum*.

Keywords: temperature, drought stress, salt stress, field capacity, pH, sowing depth.

*RESUMO - **Trianthema portulacastrum** é uma planta daninha bastante problemática para safras de verão, e observa-se a perda total de safras por causa da alta densidade desta planta daninha. Em experimentos de laboratório, foi investigado o efeito de diferentes fatores ecológicos sobre a germinação de sementes de **T. portulacastrum** coletadas em dois anos diferentes (2009 e 2005). O aumento da temperatura de 25 para 35 °C elevou a percentagem de germinação de **T. portulacastrum** de 65 para 85%, a qual, em seguida, foi reduzi da para 71,25% à temperatura de 45 °C. A máxima germinação de **Trianthema portulacastrum** ocorreu com água destilada, em comparação com soluções salinas e níveis de estresse hídrico diferentes. A germinação foi significativamente mínima com níveis de estresse salino e hídrico de 250 mM e -0,8 MPa, respectivamente. A emergência máxima (86,25%) ocorreu a 100% do nível de capacidade de campo, mas diminuiu drasticamente à medida que a capacidade de campo foi reduzida, e a emergência mínima (30%) foi registrada no nível de 25% da capacidade de campo. A menor germinação de **T. portulacastrum** foi observada com pH 5, e o aumento no pH resultou em uma maior taxa de germinação. A germinação teve índices estatísticos semelhantes quando o pH variou entre 8 e 10. A profundidade da semeadura de 6 cm reduziu a emergência de **T. portulacastrum** a zero. Foi observada a redução da emergência com o aumento da profundidade de zero para 5 cm. A emergência*

[1] Recebido para publicação em 18.9.2012 e aprovado em 18.2.2013.

[2] Department of Agronomy, University of Agriculture Faisalabad, 38040, Pakistan; [3] Department of Agronomy, University College of Agriculture, University of Sargodha, 40100, Pakistan, *Corresponding author <mmansoorjavaid@gmail.com>; [4] University College of Agriculture and Environmental Sciences, The Islamia University of Bahawalpur, Pakistan; [5] Department of Horticulture, University College of Agriculture, University of Sargodha, 40100, Pakistan.

máxima foi registrada a partir da superfície do solo (0 cm). O aumento de temperatura, salinidade, estresse hídrico, profundidade de semeadura (até 4 cm) e a diminuição da capacidade de campo aumentaram o tempo para iniciar a germinação/emergência, o tempo de 50% de germinação/emergência e tempo médio de germinação/emergência , mas o índice de germinação/emergência foi reduzido. As sementes coletadas em 2009 resultaram em maior germinação do que as sementes antigas, colhidas em 2005. O conhecimento destas informações pode ajudar no desenvolvimento de um controle eficaz de ***T. portulacastrum****.*

Palavras-chave: temperatura, estresse hídrico, estresse salino, capacidade de campo, pH, profundidade de semeadura.

INTRODUCTION

Horse purslane (*Trianthema portulacastrum*) belongs to the Aizoaceae family and is a much branched, fast growing, prostrate, succulent annual herb with ovate green leaves. Horse purslane is indigenous to South Africa, but it is widely distributed in India, Pakistan, Sri Lanka, West Asia, Africa, and tropical America (Saeed et al., 2010). It is a weed of cultivated fields and waste lands. It grows luxuriantly if water is available and it is especially problematic in maize, cotton, potato, sugarcane, pulses, fodders and vegetables, particularly during rainy season (Hazra et al., 2011). Its prostrate growth and profuse branching capacity helps it to quickly cover the soil surface and form a green carpet (Senthil et al., 2009). It has exclusively vegetative growth for a short time period of 35-40 days after emergence and then both vegetative growth and reproductive growth continue simultaneously (Das, 2008). It produces numerous small, white flowers from April to October in Pakistan, and it has high fecundity. At its high density, complete crop failure has been observed in the farmer's fields.

Several studies have reported that seed germination and seedling emergence of a species are influenced by factors such as seed age, pH, temperature, moisture, salinity and sowing depth (Chachalis & Reddy, 2000; Hossain et al., 2001; Kaya et al., 2006; Jamil et al., 2007). Salinity causes considerable decline in germination percentage and seedling growth by specific ion toxicity and osmotic effect (Taisan, 2010). The level of drought and salinity at which germination is reduced varies with species, genotype, environmental conditions, osmotic potential and specific ions (Ungar, 1991). Acidity and alkalinity have a significant effect on germination of weeds (Ramirez et al., 2012). Seed burial depth and amount of food reserve in seeds are considered important factors that affect weeds emergence under soil (Nandula et al., 2006) by affecting temperature, light and water supply (Rao et al., 2008).

The study of seed germination ecology plays an important role in checking the potential of weeds to grow under different agro-ecological conditions and in developing better management strategies for weed control. A previous study was conducted by Balyan & Bhan (1986) on germination of *T. portulacastrum* under different temperature and seeding depth, but no research has been done on other environmental factors. Therefore, the objective of this study was to determine the effect of temperature, salinity, drought stress, field capacity, pH and sowing depth on germination of *T. portulacastrum* seeds collected in two different years.

MATERIALS AND METHODS

Seed Description and Germination Test*:* *Trianthema portulacastrum* seeds were collected at maturity from non-cropped areas in the Ayub Agricultural Research Institute, Faisalabad, Pakistan in the years 2005 and 2009. Seeds were cleaned and dried for 7 days at room temperature and then stored in paper bags in laboratory at room temperature until further use. The study was carried out in the laboratory of the Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.

Germination was determined by evenly placing 25 seeds in a 9 cm diameter Petri plate containing Whatman filter paper No. 10, moistened with 5ml distilled water or a treatment solution. Seeds of *T. portulacastrum* were surface-sterilized by soaking in 10% sodium hypochlorite (NaOCl) for 5 min, followed by five rinses with distilled water before the start of each germination trial. The Petri plates were sealed with Parafilm to reduce water loss. All the experiments (except for the temperature experiment) were conducted at 35 °C with a 10h photoperiod. Germinated seeds with a radicle at least 2 mm long were counted and removed daily for a period of 2 wk.

Effect of Temperature: Germination was determined in growth chambers under constant temperatures of 25, 30, 35, 40, and 45 °C. These temperatures were selected because this weed grows from April to October in Pakistan and the temperature during this period ranges from 25 to 45 °C.

Effect of pH: Solutions with pH 5, 6, 7, 8, 9 and 10 were prepared using three buffer solutions. A 2-mM solution of MES [2-(N-morpholino) ethanesulfonic acid] was adjusted to pH 5 or 6 with 1 N NaOH. A 2-mM solution of HEPES [N-(2-hydroxy-methyl)piperazine-N-(2-ethanesulfonic acid)] was adjusted to pH 7 or 8 with 1 N NaOH. A pH 9 or 10 buffer was prepared with 2-mM tricine [N-tris (hydroxymethyl) methylglycine] and adjusted with 1 N NaOH (Chachalis & Reddy, 2000). These pH levels were selected because of the nature of Pakistan soil in which pH is mostly above 7.

Drought Stress: Aqueous solutions with osmotic potential of 0 (distilled water/control), -0.2, -0.4, -0.6 and -0.8 MPa were prepared by dissolving appropriate amounts of polyethylene glycol (PEG) 6000 in deionized water (Steuter et al., 1981).

Salt Stress: Sodium chloride solutions of 0 (distilled water), 25, 50, 75, 100, 125,150, 175, 200, 225 and 250 mM were prepared. Salinity levels were selected because of higher salt concentration in Pakistan soils.

Field capacity: To study emergence under 25, 50, 75 and 100% field capacity levels, saturated soil paste was prepared using distilled water. Half of the water used in making the paste was considered as 100% field capacity. Similarly, 25, 50 and 75% field capacity levels were maintained. Twenty five seeds were sown in 5 kg soil-filled pots.

Sowing depth: Ten seeds of *T. portulacastrum* were placed in plastic pots filled with 0.5 kg sand at 0, 1, 2, 3, 4, 5, and 6 cm depths. Initially, 100 ml distilled water was added to each pot and, after that, water was applied whenever needed. These pots were placed in the laboratory at 35 °C.

The time to obtain 50% germination or emergence (T_{50} or E_{50}) was calculated according to the following formula of Coolbear et al. (1984):

$$T_{50} \text{ or } E_{50} = t_i + \frac{\left(\frac{N}{2} - n_i\right)(t_j - t_i)}{(n_j - n_i)}$$

where N is the final number of germinated or emerged seeds and n_j and n_i are the cumulative number of seeds germinated by adjacent counts at times t_j (day) and t_i, (day) respectively, when $n_i < N/2 < n_j$.

Mean germination/emergence time (*MGT* or *MET*) was calculated according to the equation of Ellis & Roberts (1981):

$$MGT \text{ or } MET = \frac{\sum Dn}{\sum n}$$

where n is the number of seeds that had germinated on day D and D is the number of days counted from the beginning of germination. The germination/emergence index (*GI* or *EI*) was calculated as described by the Association of Official Seed Analysis (AOSA, 1983) using the following formula:

$$GI \text{ or } EI = \frac{No\ of\ germinated \text{ or } emerged\ seeds}{Days\ of\ first\ count} + \ldots + \frac{No\ of\ germinated \text{ or } emerged\ seeds}{Days\ of\ final\ count}$$

Statistical analysis

A completely randomized design with four replications was used in all experiments. Except for the experiments of germination percentage of *T. portulacastrum* in salt and osmotic stress and the experiments of

T. portulacastrum emergence percentage in burial depth and field capacity, all data were subjected to analysis of variance (ANOVA) with the use of SAS (2002). When a significant difference was found by ANOVA at 5% level of probability, the treatments were identified using Fisher's LSD (Steel et al., 1997). A square-root arcsine transformation was used to stabilize the variances for percentage data before analysis (Bartlett, 1947). Nonlinear regression analysis was used to determine how NaCl, osmotic stress, burial depth or field capacity affected percentage of germination or emergence. Germination (%) values at different concentrations of NaCl and osmotic potential were fitted to a functional three-parameter logistic model using Sigma Plot 2008 (version 11.0). The model fitted was $G(\%) = G_{max}/[1+(x/x_{50})^{Grate}]$, where G is total germination (%) at concentration or osmotic potential x, G_{max} is maximum germination (%), x_{50} is NaCl concentration or osmotic potential for 50% inhibition of maximum germination and G_{rate} indicates the slope. A three-parameter logistic model $\{E\ (\%) = E_{max}/[1+(x/x_{50})^{E}{}_{rate}]\}$ was fitted to the *T. portulacastrum* seedling emergence (%) obtained at different burial depth of 0 to 10 cm and field capacity of 100 to 25% where E is total seedling emergence (%) at burial depth of field capacity x, E_{max} is maximum seedling emergence (%), x_{50} is burial depth of field capacity for 50% inhibition of maximum seedling emergence and E_{rate} indicates the slope.

RESULTS AND DISCUSSION

Effect of temperature: Figure 1A shows the germination percentage of one-year-old and five-year-old *T. portulacastrum* seeds affected by different temperatures. Maximum germination of both types of seeds was

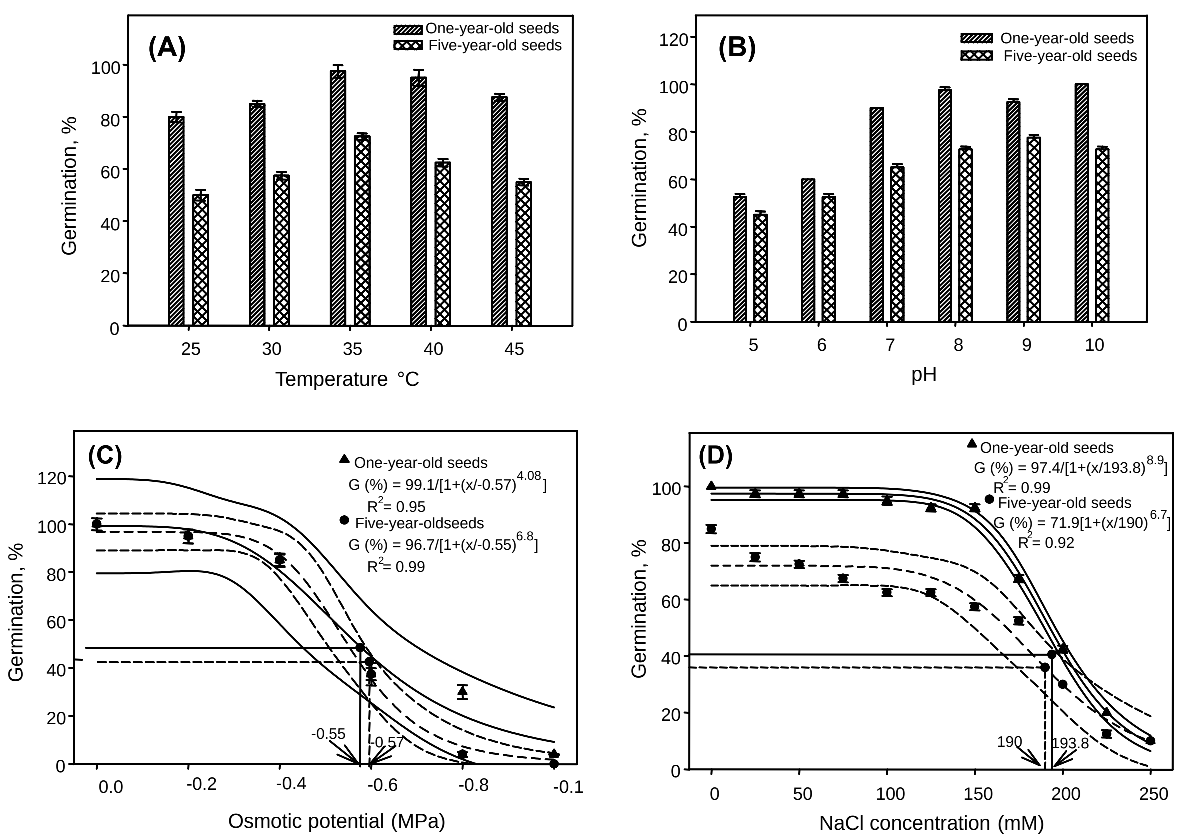

Figure 1 - Effect of temperature (A), pH (B), osmotic potential (C) NaCl concentration (D) on germination of *T. portulacastrum*. For Figures C and D, bold lines represent a three-parameter logistic model fitted to the data for *T. portulacastru*, and thin lines show 95% confidence intervals. Continuous lines (————) are used for one-year-old seeds and dash lines (- - - -) for five-year-old seeds. Vertical lines represent ± standard error of the mean if greater than the size of symbol.

recorded at 35 °C temperature. An increase in temperature from 25 to 35 °C increased germination percentage from 65 to 85%. After 35 °C, germination started to decrease and was reduced to 71.25 % at 45 °C. Time to start germination, time to 50% germination and mean germination time were lower in one-year-old seeds than five-year-old seeds (Table 1). Minimum time to start germination (1.00 d), time to 50% germination (1.30 d) and mean germination time (1.99 d) were observed at 40 °C (Table 1). Maximum germination index (8.21) was found at 40 °C. This study concluded that an increase in temperature increased germination of *T. portulacastrum.* It is presumed that metabolic activities initiating germination were higher at 35 and 40 °C. Gill & Brar (1981) reported 40 °C for maximum germination of *T. monogyna*. In *T. portulacastrum*, maximum germination (90%) was observed at 35 °C (Balyan & Bhan, 1986). Germination of *Polygonum persicaria* was also higher under high temperatures and maximum germination was observed at 30 °C (Vleeshouwers, 1998).

Effect of pH: Germination % of one-year-old *T. portulacastrum* seeds was higher than that of five-year-old seeds at different pH levels (Figure 1B). Germination % of both types of seeds was lower under acidic condition than under alkaline or neutral condition. Effect of pH showed maximum germination % in alkaline pH values (8-10). Data shown in Table 2 revealed that germination index was lower while time to 50% germination and mean germination time were higher in five-year-old seeds than one-year-old seeds. Minimum time to start germination, time to 50% germination and mean germination time were observed in alkaline pH values. Germination index was found maximum in pH 9-10. This study concluded that an increase in pH towards alkaline increased germination of *T. portulacastrum.* Seed germination of *Campsis radicans* was greater than 60% over a pH range from 5 to 9 with higher germination at pH 7 and above (Chachalis & Reddy, 2000). Germination of *Conyza canadensis* and *Lolium multiflorim* was 19 to 36%, 37–87%, respectively over a wide range of pH from 4 to 10 but maximum germination was observed at pH 7 (Nandula et al., 2006, 2009). High seed germination of *T. portulacastrum* over a broad pH range indicates that pH is not a limiting factor for germination in most soils.

Drought Stress: An increase in osmotic potential from 0 to -0.8 MPa decreased germination of *T. portulacastrum* from 100 to 20 and 85.5 to 25% in one-year-old and five-year-old seeds, respectively (Figure 1C).

Table 1 - Effect of temperature (°C) on different germination traits of *T. portulacastrum*

Treatment	Time to start germination (days)	Time to 50% germination (days)	Mean germination time (days)	Germination index
Seed age				
One-year-old seeds	1.10 b	1.33 b	2.05 b	9.64 a
Five-year-old seeds	1.80 a	2.50 a	3.04 a	3.62 b
LSD value	0.22	0.26		0.61
Temperature (°C)				
25	2.13 a	2.41 a	2.96 a	4.61 d
30	1.75 b	2.25 a	2.82 ab	5.91 c
35	1.38 c	2.18 a	2.59 bc	7.44 ab
40	1.00 d	1.30 b	1.99 d	8.21 a
45	1.00 d	1.44 b	2.35 c	6.95 b
LSD	0.35	0.41	0.29	0.96

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (p<0.05).

Table 2 - Effect of pH on different germination traits of *T. portulacastrum*

Treatment	Time to start germination (days)	Time to 50% germination (days)	Mean germination time (days)	Germination index
Seed age				
One-yearold seeds	1.00	1.28 B	1.94 b	8.62 a
Five-year-old seeds	1.08	2.14 A	3.05 a	4.43 b
LSD value	NS	0.09	0.11	0.37
pH levels				
5	1.12	1.86 ab	2.42 bc	3.66 c
6	1.12	2.00 a	3.16 a	3.94 c
7	1.00	1.57 c	2.42 bc	7.41 b
8	1.00	1.45 c	2.26 cd	7.59 b
9	1.00	1.59 c	2.21 d	8.27 a
10	1.00	1.77 b	2.50 b	8.30 a
LSD	NS	0.16	0.19	0.64

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (p<0.05).

Germination was completely inhibited at an osmotic potential of -0.1 MPa in both types of seeds. A three-parameter logistic model {G (%) = $99.1/[1+(x/-0.57)^{4.08}]$} showed that an osmotic potential of -0.57 was required for 50% inhibition of maximum germination of one-year-old seeds (Figure 1C). Similarly, in five-year-old seeds, the fitted model {G (%) = $96.7/[^{1+}(x/-0.55)^{6.08}]$} indicated that the osmotic potential required for 50% inhibition of maximum germination was -0.55 MPa. Drought stress significantly affected the different germination traits of *T. portulacastrum* collected in two different years (Table 3). Germination index was higher in one-year-old seeds while time to start germination, time to 50% germination and mean germination time were higher in five-year-old seeds. Minimum time to start germination (1.0 d), time to 50 % germination (1.20 d) and mean germination time (1.95 d) were observed in the control. When drought stress was increased to -0.8 MPa, time to start germination, time to 50 % germination and mean germination time increased to 2.0 d, 2.03 d and 2.93 d, respectively. Minimum germination index (1.51) was observed at -0.8 MPa compared with 9.17 in the control (Table 3). This study concluded that an increase in drought stress decreased germination of *T. portulacastrum.* A decrease in water potential gradient between seed and surrounding media adversely affected germination. In other words, water deficit conditions decreased germination because of inadequate water uptake by seeds (Dodd & Donovan, 1999). Similar results were observed by Nandula et al. (2009) for *Lolium multiflorim,* whose germination was reduced from 79 to 8% when drought stress increased from 0 to -0.8 MPa. Taisan (2010) reported that drought stress decreased and delayed germination of *Pennisetum divisum* and germination was only 10% at drought stress of -0.8 MPa. The significant reduction in germination of *T. portulacastrum*, even at moderate drought stress levels, is in contradiction to the results of Singh (2009), who reported that moderate stress intensities only delayed germination, whereas the highest concentration of PEG reduced final germination percentages of *Sorghum halepense.*

Salt Stress: Salinity significantly affected the different germination traits of *T. portulacastrum* seeds collected in two different years (Figure 1D and Table 4). Germination percentage was higher in one-year-old seeds than in five-year-old seeds (Figure 1D). Germination % of one-year-old seeds was higher than 80% up to 150 mM NaCl concentration. After this level, germination

Table 3 - Effect of drought on different germination traits of *T. portulacastrum*

Treatment	Time to start germination (days)	Time to 50% germination (days)	Mean germination time (days)	Germination index
Seed age				
One-year-old seeds	1.00 b	1.24 b	2.38 b	6.27 a
Five-year-old seeds	1.85 a	2.18 a	2.66 a	4.30 b
LSD value	0.13	0.04	0.13	0.22
Osmotic potential (MPa)				
0 (Control)	1.00 c	1.20 d	195 c	9.17 a
-0.2	1.25 b	1.85 b	2.41 b	7.30 b
-0.4	1.37 b	1.56 c	2.51 b	6.04 c
-0.6	1.50 b	1.92 b	2.80 a	2.40 d
-0.8	2.00 a	2.03 a	2.93 a	1.51 e
-1.0	NG	NG	NG	NG
LSD	0.25	0.07	0.24	0.41

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (p<0.05). NG = not germinated.

Table 4 - Effect of salinity on different germination traits of *T. portulacastrum*

Treatment	Time to start germination (days)	Time to 50% germination (days)	Mean germination time (days)	Germination index
Seed age				
One-year-old seeds	2.20	2.35 b	2.51 b	5.74 a
Five-year-old seeds	2.64	2.97 a	3.08 a	3.92 b
LSD value	NS	0.04	0.03	0.18
NaCl cocentrations (mM)	1.00 h			
0 (Control)	1.00 h	1.34 j	1.51 k	8.98 a
25	1.00 h	1.45 i	1.61 j	8.32 b
50	1.50 g	1.79 h	1.93 i	6.51 c
75	2.00 f	2.08 g	2.20 h	6.47 c
100	2.00 f	2.29 f	2.41 g	6.36 c
125	2.00 f	2.43 e	2.61 f	5.46 d
150	3.00 e	2.95 d	3.03 e	5.21 d
175	3.50 c	3.02 d	3.22 d	3.17 e
200	3.25 d	3.30 c	3.48 c	1.99 f
225	3.87 b	4.09 b	4.19 b	0.51 g
250	4.56 a	4.56 a	4.56 a	0.14 g
LSD	0.17	0.10	0.08	0.43

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (p<0.05).

decreased progressively with increased salinity level, and only 10% germination was observed at the highest level of salinity (250 mM NaCl concentration). A three-parameter logistic model $\{G\,(\%) = 97.4/[1+(x/193.8)^{8.9}]\}$ was fitted to the germination data of one year old *T. portulacastrum* seeds (Figure 1D). The model equation showed that germination of one-year-old *T. portulacastrum* seeds was decreased by 50% of maximum germination at NaCl concentration of 193.8 mM. Similarly, germination of five-year-old seeds decreased with increased NaCl concentration. According to the fitted model, maximum germination (71.9%) occurred at 0 mM, and 190 mM NaCl concentration was required to inhibit 50% of maximum germination of five-year-old *T. portulacastrum* seeds (Figure 1D). At different salinity levels, one-year-old and five-year-old seeds have the same time to start germination. Germination index was higher while time to 50% germination and mean germination time were lower in one-year-old seeds compared with five-year-old seeds (Table 4). Minimum time to start germination (1.0 d), time to 50% germination (1.34 d) and mean germination time (1.51 d) were observed at 0 mM. As salinity increased, these germination parameters were increased. Maximum germination index (8.98) was also found in the control, and it was reduced to 0.14 at 250 mM. This study concluded that an increase in salinity decreased germination of *T. portulacastrum.* Decreased germination under salinity could result from the toxic or osmotic effect of NaCl, which prevents seed imbibition (Tobe et al., 1999). Salinity increases the production of ROS (reactive oxygen species) which damage DNA and proteins (Gossett et al., 1994). Chachalis & Reddy (2000) observed similar results for *Campsis radicans* in which germination was decreased with increasing salinity levels, and it was only 20% at 160 mM. A decrease in germination with increased salinity has also been reported in *Thymus maroccanus* Ball by Belaqziz et al. (2009), who observed no germination at 200 mM salinity level. Kaydan & Yagmur (2008) reported that stress produced by NaCl delayed germination percentage of triticale. It is assumed that effect of salinity on seed germination depends on weed species.

Field capacity: Emergence of one year old *T. portulacastrum* seeds was higher than five-year-old seeds (Figure 2A). When field capacity decreased from 100 to 25%, emergence decreased from 96 to 35% and 77 to 25% in one-year-old and five-year-old seeds, respectively. The fitted model $\{E\ (\%) = 96.5/[1+(x/66.5)^{2.8}]\}$ showed that field capacity is 66.5% for 50% inhibition of the maximum emergence in one-year-old seeds. Model $\{E\ (\%) = 75.5/[1+(x/64)^{4.2}]\}$ showed that, in five–year-old seeds, 50% inhibition of maximum emergence occurred at 64% field capacity. Emergence index was higher while time to start emergence, time to 50% emergence and mean emergence time were lower in one-year-old seeds compared with five-year-old seeds (Table 5).The significantly minimum time to start emergence (2.12 d), time to 50%

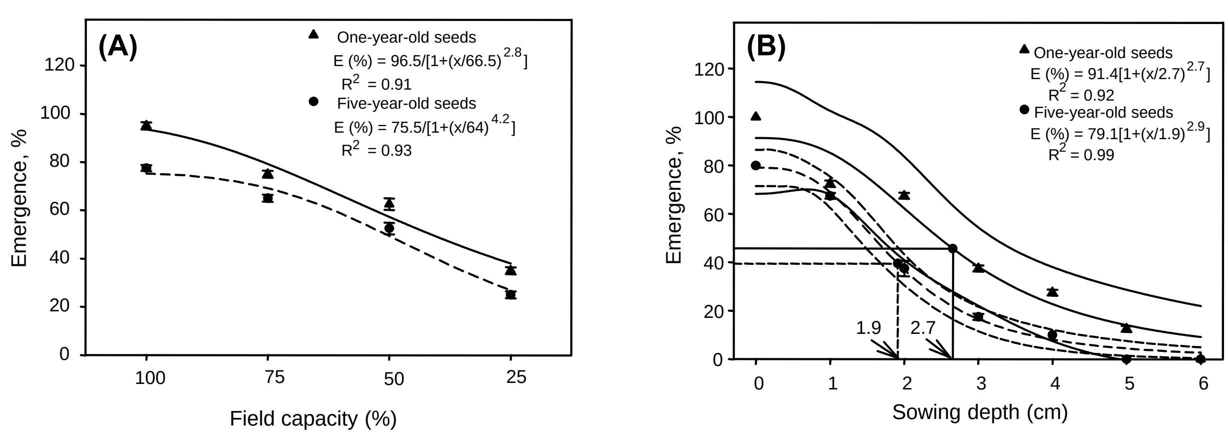

Figure 2 - Effect of field capacity (A) and sowing depth (B) on seed germination of *T. portulacastrum*. Bold lines represent a three-parameter logistic model fitted to the data for *T. portulacastrum*, and thin lines in b show 95% confidence intervals. Continuous lines (___) are used for one-year-old seeds and dash lines (- - - -) for five-year-old seeds. Vertical bars represent ± standard error of the mean if greater than the size of symbol.

emergence (2.62 d), mean emergence time (2.80 d) and higher emergence index (5.70) were observed at 100% field capacity. Decrease in field capacity significantly increased time to start emergence, time to 50% emergence and mean emergence time. The results revealed that emergence of *T. portulacastrum* decreased by decreasing field capacity. The decrease in emergence under low moisture conditions probably happened because there was not enough water for seed imbibition and softening so that seed coats could germinate. Similar results were observed by Hussain et al. (2003) with minimum emergence of *Amaranthus viridis* at 25% field capacity and by Laubhan & Shaffer (2006) with maximum emergence of *Cirsium arvense* and *Lepidium latifolium* under 100% FC. These results are further supported by Aboyami & Adeyini (2005), who observed that emergence was lower and time to start emergence was higher under 25% field capacity.

Sowing depth: One-year-old seeds showed higher emergence % at varying sowing depths compared with of five-year-old seeds. Emergence % was < 79% in both types of seeds when placed on soil surface, and it decreased with increased sowing depth (Figure 2B). In five-year-old seeds, no emergence occurred at a sowing depth of 5 cm or deeper. A three-parameter logistic model was fitted to the seedling emergence data of *T. portulacastrum* collected at two different times. The fitted model estimated that depths of 2.7 and 1.9 cm were required to inhibit 50% seedling emergence of maximum seedling emergence in one-year-old and five-year-old seeds, respectively (Figure 2B). Emergence index was higher in one-year-old seeds while time to start emergence, time to 50% emergence and mean emergence time were lower compared with five-year-old seeds (Table 6). Minimum time to start emergence (3.50 d), time to 50% emergence (3.75 d), mean emergence time (3.75) were observed in seeds that had been placed on soil surface (0 cm). These parameters were increased with an increase in sowing depth. Higher emergence index (4.56) was observed in seeds that had been placed on soil surface, and it decreased with increasing depth and was reduced to 0 at 6 cm (Table 6). This study concluded that increasing sowing depths decreased emergence of *T. portulacastrum.* Lower germination under greater soil depth was due to less vigorous seeds because small seeds have fewer food reserves (Lafond & Baker, 1986). Reduced emergence may also be due to poor oxygen exchange surrounding the buried seeds (Benvenuti, 2003). Decreased emergence as a result of increased planting depth has also been reported in *Caperonia palustris* (Koger et al., 2004), in which maximum germination (67%) was found on soil surface. Nandula et al.

Table 5 - Effect of field capacity on different emergence traits of *T. portulacastrum*

Treatment	Time to start germination (days)	Time to 50% germination (days)	Mean germination time (days)	Emergence index
Seed age				
One year old seeds	3.12 b	3.74 b	4.01 b	4.56 a
Five years old seeds	4.00 a	4.46 a	4.68 a	3.53 b
LSD value	0.39	0.18	0.19	0.21
Field capacity (%)				
100	2.12 d	2.62 d	2.80 d	5.70 a
75	3.12 c	3.60 c	3.74 c	4.88 b
50	4.12 b	4.63 b	4.81 b	3.50 c
25	4.87 a	5.55 a	6.05 a	2.08 d
LSD	0.56	0.26	0.26	0.29

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (p<0.05).

Table 6 - Effect of sowing depth on different emergence traits of *T. portulacastrum*

Treatment	Time to start emergence (days)	Time to 50% emergence (days)	Mean emergence time (days)	Emergence index
Seed age				
One-year-old seeds	4.42 a	4.10 a	5.58 a	2.17 a
Five-year-old seeds	4.00 b	4.65 b	5.07 b	1.43 b
LSD value	0.20	0.23	0.23	0.12
Sowing depth (cm)				
0	3.50 e	3.75 f	3.75 d	4.56 a
1	4.37 d	4.81 e	5.89 c	3.88 b
2	4.87 c	5.29 d	6.90 ab	2.43 c
3	6.25 b	6.18 c	6.78 b	0.93 d
4	6.87 a	6.65 b	6.64 b	0.63 e
5	3.62 e	7.47 a	7.31 a	0.16 f
6	NE	NE	NE	NE
LSD	0.38	0.44	0.44	0.22

A statistical analysis (ANOVA) was made for each treatment and for each column. The values followed by different letters are significantly different at (P<0.05). NE = not emerged.

(2009) observed similar results for *Lolium multiflorim*in, whose emergence decreased with increasing planting depth, and maximum emergence (80%) was observed for seeds placed on soil surface. Seeds of *Euphorbia heterophylla* also showed maximum emergence on soil surface. Moreover, seeds emerged earlier at 1-2 cm depth than at 5 cm depth or deeper (Etejere & Okoko, 1989).

This study concluded that different ecological factors such as temperature, salinity, drought, field capacity, pH and sowing depth play an important role in germination of *T. portulacastrum*, which has potential to germinate/emerge under varying ecological conditions. This study will be helpful in predicting suitable environments for germination of this weed, thus making it much easier to prevent the weed from spreading into new areas.

LITERATURE CITED

ABOYAMI, Y. A.; ADEYINI, A. M. Comparative germination responses of cowpea and maize genotypes of soil moisture content. **Agrosearch.**, v. 7, n. 1-2, p. 34-42, 2005.

ASSOCIATION OF OFFICIAL SEED ANALYSIS – AOSA. Rules for testing seeds. **J. Seed Sci. Technol.**, v. 12, n. 1, p. 1-112, 1990.

BALYAN, R. S.; BHAN, V. M. Germination of horse purslane (*Trianthema portulacastrum*) in relation to temperature, storage conditions and seeding depths. **Weed Sci.**, v. 34, n. 4, p. 513-515, 1986.

BARTLETT, M. S. The use of transformations. **Biometrics**, v. 3, n. 1, p. 39-52, 1947.

BELAQZIZ, R. et al. Salt stress effect on germination, growth and essential oil content of *Endemic thyme* species in morocco (*Thymus maroccanus* ball.). **J. Appl. Sci. Res.**, v. 5, n. 7, p. 858-863, 2009.

BENVENUTI, S. Soil texture involvement in germination and emergence of buried weed seeds. **J. Agron.**, v. 95, n. 1, p. 191-198, 2003.

CHACHALIS, D.; REDDY, K. N. Factors affecting *Campsis radicans* seed germination and seedling emergence. **Weed Sci.**, v. 48, n. 2, p. 212-216, 2000.

COOLBEAR, P. et al. The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. **J. Exper. Bot.**, v. 35, n. 11, p. 1609-1617, 1984.

DAS, T. K. **Basics and applications**. New Delhi: Jain Brothers, 2008. 901 p.

DODD, G. L.; DONOVAN, L. A. Water potential and ionic effects on germination and seedling growth of two cold desert shrubs. **Am. J. Bot.**, v. 86, n. 8, p. 1146-1153, 1999.

ELLIS, R. A.; ROBERTS, E. H. The quantification of aging and survival in orthodox seeds. **Seed Sci. Technol.**, v. 9, n. 2, p. 373-409, 1981.

ETEJERE, E. O.; OKOKO, T. O. Seed production, germination and emergence of *Euphorbia heterophylla* L. **Nigerian J. Bot.**, v. 2, n. 1, p. 143-147, 1989.

GILL, H. S.; BRAR, L. S. The growth and development of *T. monogyna* under self induced competition. **Indian J. Ecol.**, v. 8, n. 2, p. 213-216, 1981.

GOSSETT, D. R. et al. Antioxidants response to NaCl stress in salt tolerant and salt sensitive cultivars of cotton (*Gossypium hirsutum* L.). **Crop Sci.**, v. 34, n. 3, p. 706-714, 1994.

HAZRA, D. et al. Interference and economic threshold of horse purslane (*Trianthema portulacastrum*) in soybean cultivation in northern India. **Weed Biol. Manag.**, v. 11, n. 2, p. 72-82, 2011.

HOSSAIN, M. A. et al. Influence of temperature levels and planting time on sprouting of rhizome-bud and biomass production of torpedo grass *(Panicum repens* L.) in Okinawa Island, southern Japan. **Weed Biol. Manag.**, v. 1, n. 3, p. 164-169, 2001.

HUSSAIN, F. et al. Some auto ecological studies on *Amaranthus viridis* L. **Pakistan J. Weed Sci. Res.**, v. 9, n. 12, p. 117-124, 2003.

JAMIL, M. et al. Salinity reduced growth PS2 photochemistry and chlorophyll content in radish. **Agric. Sci.**, v. 64, n. 2, p. 111-118, 2007.

KAYA, M. D. et al. Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). **Eur. J. Agron.**, v. 24, n. 4, p. 291-295, 2006.

KAYDAN, D.; YAGMUR, M. Germination, Seedling growth and relative water content of shoot in different seed sizes of *Triticale* under osmotic stress of water and NaCl. **Afr. J. Biotechnol.**, v. 7, n. 16, p. 2862-2868, 2008.

KOGER, C. H. et al. Factors effecting seed germination, seedling emergence and survival of texa weed (*Caperonia palustris*). **Weed Sci.**, v. 52, n. 6, p. 989-995, 2004.

LAFOND, G. P.; BAKER, R. J. Effects of genotype and seed size on speed of emergence and seedling vigor in nine spring wheat cultivars. **Crop Sci.**, v. 26, n. 2, p. 341-346, 1986.

LAUBHAN, M. K.; SHAFFER, T. L. Seed germination of *Cirsium arvense* and *Lepidiu mlatifolium*: implications for management of montane wetlands. **Wetlands**, v. 26, n. 1, p. 69-78, 2006.

NANDULA, V. K. et al. Seed germination difference between glyphosate resistant and susceptible Italian ryegrass population. **Weed Technol.**, v. 31, n. 2, p. 123-133, 2009.

NANDULA, V. K. et al. Factors affecting germination of horseweed (*Conyza Canadensis*). **Weed Sci.**, v. 54, n. 5, p. 898-902, 2006.

RAMIREZ, A. H. et al. Germination and emergence characteristics of common beggar's-tick (Bidens alba). **Weed Sci.**, v. 60, n. 3, p. 374-378, 2012.

RAO, N. et al. Influence of environmental factors on seed germination and seedling emergence of American sloughgrass (*Bechmannia syzigachne*). **Weed Sci.**, v. 56, n. 4, p. 529-533, 2008.

SAEED, M. et al. Interference of horse purslane (*Trianthema portulacastrum* L.) with maize (*Zea mays* L.) at different densities. **Pakistan J. Bot.**, v. 42, n. 1, p. 173-179, 2010.

STATISTICAL ANALYSIS SYSTEMS – SAS. **SAS procedures guide**. version 9. Cary, Statistical Analysis Systems Institute, 2002.

SENTHIL, A. et al. Identification of threshold level of horse purslane (*Trianthema portulacastrum*) in irrigated cowpea (*Vigna unguiculata*). **Indian J. Crop Sci.**, v. 4, n. 1, p. 141-143, 2009.

SINGH, S. Effect of temperature and water potential on germination of twelve weed species. **Indian J. Weed Sci.**, v. 41, n. 3-4, p. 113-126, 2009.

STEEL, R. G. D. et al. **Principles and procedures of statistics**. 3.ed. New York: McGraw Bill Book, 1997. p. 178-198.

STEUTER, A. A. et al. Water potential of aqueous polyethylene glycol. **Plant Physiol.**, v. 67, n. 1, p. 64-67, 1981.

TAISAN, W. A. Competitive effects of drought and salt stress on germination and seedling growth of *Pennisetum divisum* (Gmel) Henr. **Am. J. Appl. Sci.**, v. 7, n. 5, p. 640-646, 2010.

TOBE, K. et al. Effect of NaCl on seed germination of five non halophytic species from a Chinese desert environment. **Seed Sci. Technol.**, v. 27, n. 2, p. 851-863, 1999.

UNGAR, I. **Ecophysiology of vascular halophytes**. Boca Raton: CRC Press, 1991. p. 209.

VLEESHOUWERS, L. M. The effect of seed dormancy on percentage and rate germination in *Polygonum persicaria*, and its relevance for crop-weed interaction. **Ann. Appl. Biol.**, v. 132, n. 2, p. 289-299, 1998.