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Effect of Temperature and Water Potential on Germination of Twelve Weed Species

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ABSTRACT

Growth cabinet studies were conducted on the effect of water potential and interaction of temperature and water potential on germination of Brazil pusley, common ragweed, Florida beggarweed, hairy beggarticks, ivyleaf morningglory, Johnsongrass, prickly sida, redroot pigweed, sicklepod, strangler vine, tall morningglory and yellow nutsedge. Decreasing water potential from 0 to -0.1, -0.2 -0.4 and -0.8 MPa caused 12, 32, 75 and 96% reduction in germination of the test species, 3 WAS. A lower water potential of -0.1 MPa resulted in significant reduction in germination of common ragweed, strangler vine, hairy beggarticks and redroot pigweed. Decreasing water potential further to -0.4 MPa caused 77 to 100% inhibition in germination of all the test species, except Florida beggarweed, yellow nutsedge and tall morningglory. No weed seed could germinate at -1.2 MPa, whereas 28, 9 and 3% seeds of Florida beggarweed, yellow nutsedge and tall morningglory were able to germinate at -0.8 MPa. Water stress of -0.1 and -0.2 MPa delayed the germination of Johnsongrass by one and two weeks, respectively. Germination of tall morningglory, Florida beggarweed, ivyleaf morningglory, sicklepod and prickly sida was faster than Brazil pusley, strangler vine and beggarticks. Water stress of -0.2 MPa reduced the germination of ivyleaf morningglory and prickly sida, whereas tall morningglory, Florida beggarweed and sicklepod required -0.4 MPa osmotic potential to significantly reduce germination. Increasing the temperature from 15 to 20 and 30^{O}C increased germination of weed species from 11 to 22 and 34%, respectively. Increasing water stress from -0.1 to -05 and -1.0 MPa resulted in 37, 6 and 0.3% germination compared to 47% with no water stress. Increasing temperature from 15 to 20 and 30^{O}C resulted in 18, 36 and 56% germination at -0.1 MPa osmotic potential. Lower temperature and water stress was more inhibitory than high temperature and increased water stress to many weeds species. Decreased osmotic potential of -1.0 MPa resulted in complete germination inhibition of all species, except Florida beggarweed (11%). An increase in temperature of 5 or 10^{O}C increased germination of tall morningglory from 10 to 34 and 43% at -0.5 MPa osmotic potential. At -0.5 MPa, Florida beggarweed had no germination at 15 or 20^{O}C compared to 43% at 30^{O}C, which was similar to 20^{O}C and lower water stress (-0.1 MPa).

Key words : Weed biology, management, germination, temperature, water stress

INTRODUCTION

Knowledge and prediction of weed seedling emergence patterns are critical in weed management programmes. Water stress during seed development has been found to reduce dormancy of *Sorghum halepense* seed through modifications in glumes properties which resulted in an enhancement of their permeability to oxygen diffusion (Benech-Arnold *et al*., 1992). Seed dormancy is a major factor influencing the timing of seedling emergence and once dormancy is broken, environmental conditions determine the rate of germination and seedling emergence. Crop-weed competition is largely governed by the emergence of weeds relative to the crops. Seedling emergence patterns in the field are largely generated by the influence of soil water potential on a critical event i. e. the initiation of radicle growth that determines the base water potential for germination. Above this base, the mean rate and distribution of seedling emergence are largely determined by temperature (Finch-Savage and Phelps, 1993). Seed imbibition rate and germination level normally decrease as the surrounding water potential decreases; the critical hydration level for seed germination is species-specific (Evans and Etherington 1990).

Griffin *et al*. (1989) found that under adequate soil moisture, soybean was more competitive than Florida beggarweed (*Desmodium tortuosum*), whereas reverse was true under water stress. Contrastly, *Eclipta prostrata* was found to be more sensitive than rice to moisture stress (Lee and Moody, 1988). On the other hand, *Dactyloctenium aegyptium* was able to germinate at

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-0.6 MPa water potential, but soybean failed to germinate at this moisture stress (Hoveland and Buchanan, 1973). Sauerborn *et al*. (1988) found that germination of several tropical weeds decreased with a decreasing osmotic potential, but *Ludwigia hyssopifolia*, *Alopcurus myosuroides* and *Chenopodium album* seed were able to germinate at -1.0 MPa, whereas buffalobur (*Solanum rostratum*) was able to germinate even at higher water stress of -1.1 MPa (Wei *et al.* 2009).

Hoveland and Buchanan (1973) studied germination response of several crops and weeds to artificial drought using polyethylene glycol (osmotic pressures of 0, -0.3, -0.6 and -1.0 MPa) and found that pearl millet was most tolerant to simulated drought with 40% seed germinating after 24 h at -1.0 MPa, whereas soybean was most sensitive to moisture stress and only 31% seed germinated after 96 h at -0.3 MPa and no germination at -0.6 or -1.0 MPa. None of the weed species or crops germinated under simulated drought, but most germinated better than soybeans. *Ipomoea lacunosa* was the most tolerant weed species followed by *Sida spinosa* and *Cassia obtusifolia*, whereas *Sesbania exaltata* was least tolerant.

This shows greater role of soil moisture on weed seed emergence and their survival. Soil water status not only determines weed seed germination, but also governs growth and competition. Under moderate water stress, *Bidens pilosa*, diverted energy for reproductive process, but under severe stress it was diverted towards vegetative growth with a substantial increase in the ratio of root to shoot (Capote *et al*., 1986).

Environmental factors such as temperature, moisture, light and pH regulate seed germination in the soil (Taylorson, 1970; Moore *et al*., 1994). Temperature, light and water potential regulate secondary dormancy of annual weeds affecting their germination (Taylorson, 1972, 1982; Khan and Karssen, 1980) and survival when environmental conditions are not favourable (Baskin and Baskin, 1989).

Temperature strongly influences length of time between the start of imbibition and the beginning of germination. Another major factor in determining seed germination is soil moisture. Previous research has shown that some crop seed germination is affected only slightly with moisture tensions of -0.05 to -0.3 MPa (Cardwell, 1984), whereas *Euphorbia heterophylla* germination was not reduced until soil moisture tension reached -0.8 MPa (Brecke, 1995). Yankeeweed (*Eupatorium compostifolium*) and dogfennel (*Eupatorium capillifolium*) were moderately tolerant to water stress, but yankeeweed tolerated higher water stress than dogfennel (MacDonald *et al*., 1992). Specific variations in germination of weed seeds (*Sida spinosa* and *S. rhombifolia; Cyperus iria* and *C. difformis*) have been observed under different moisture levels (Smith *et al*., 1992; Chauhan and Johnson, 2010). In the field, availability of water is a limiting factor for germination. The ability of a plant species to efficiently absorb water under less than optimum moisture conditions can play a significant part in the ecology of that plant. Barnyardgrass was not a serious problem in the southern great plains because of its inability to germinate under dry conditions (Wiese and Davis, 1967); however, they observed that it was becoming a problem in frequently irrigated crops. Hunter and Erickson (1952) observed that seed must reach a specific per cent moisture before germination. Different species can reach this optimum moisture percentage at different moisture tensions in soils. Germination of *Avena fatua* and *Echinochloa crus-galli* was significantly reduced at -0.5 MPa, whereas wheat was not affected at this moisture stress (Boyd and Van Acker, 2004). Weed seed response to moisture stress varies within close related species. An osmotic stress of -0.2 MPa reduced *Sida spinosa* germination, whereas -0.4 MPa was necessary to reduce *S. rhombifolia* germination (Smith *et al*., 1992).

Seeds of some vegetables and crops when subjected to an osmotic potential of -0.5 to -1.2 MPa at 10 to 15^{O}C have found to increase germination on subsequent transfer to water (Michel and Kaufmann, 1973; Khan *et al*., 1978) which shows the effect of alternating moisture. High temperature and osmotic potential have also been reported to impose secondary dormancy in *Chenopodium bonus-henricus* seeds (Khan and Karssen, 1980). Germination of *Amaranthus retroflexus* increased by 17% by increasing temperature from 30 to 35^{O}C under same moisture stress, which shows that moisture stress at favourable temperature was less inhibitory than extreme temperature (Habib and Morton, 1987).

The combined effect of temperature and moisture stress on weed germination has not previously been reported. The main objective of the present work was to determine the effect of environmental factors and interactions of temperature and water potential on germination of 12 weeds species. The results of this study can be used to predict behaviour of weed seed germination as influenced by moisture and temperature which is helpful in developing a model for effective weed management strategy.

MATERIALS AND METHODS

Plant Material

Weed species of tall morningglory, *Ipomoea purpurea* L. (PHBPU); Florida beggarweed, *Bidens pilosa* L. var. radiata Sch. Bip. (BIDPI); Brazil pusley, *Richardia brasiliens* Moq. (RCHBR); ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. (IPOHE); Johnsongrass, *Sorghum halepense* (L.) Pers. (SORHA); strangler vine, *Morrenia odorata* (H & A). Lindl. (MONOD); redroot pigweed, *Amaranthus retroflexus* L. (AMARE); common ragweed, *Ambrosia artemisiifolia* L. (AMBEL); sicklepod, *Cassia obtusifolia* L. (CASOB); hairy beggarticks, *Bidens pilosa* L. (BIDPI); prickly sida, *Sida spinosa* L. (SIDSP) and yellow nutsedge, *Cyperus esculentus* L. (CYPES) were used for the present studies carried out at University of Florida's Citrus Research and Education Centre, Lake Alfred (USA).

Water Potential Studies

Polyethylene glycol is the most commonly preferred chemical to impose water stress because it is metabolically inactive (Hoveland and Buchanan, 1973; Hohl and Peter, 1991) and its large molecular mass prevents entry into the seed (Berkat and Briske, 1982), also it forms a colloidal solution that produces effects similar to those caused by the matric properties of soil particles (Hadas, 1977). The 12 weed species listed above were subjected to germination test using aqueous solution of polyethylene glycol (PEG) 8000 (Carbowax® PEG 8000, Fischer Scientific, Fair Lawn, NJ 07410). Ten seeds of each species were placed in Petri dishes with two layers of Whatman No. 4 filter papers and 7 ml solution of PEG 8000 was added to each Petri dish. Osmotic potential of -0.1, -0.2, -0.4, -0.8 and -1.2 MPa was created for 30^{O}C temperature using the equation of Michel and Kaufmann (1973) as described below :

$$Y = -(1.18 \times 10^{-2})\,C - (1.18 \times 10^{-4})\,C^2 + (2.67 \times 10^{-4})\,CT + (8.39 \times 10^{-7})\,C^2T$$

Where, C = the concentration of PEG-8000 in g/kg H_2O and T = temperature in degree C.

Petri dishes were shifted to growth cabinets maintained at 30/20^{O}C (day/night) for germination test. Fresh solutions were prepared for subsequent watering. There were four replicated Petri dishes for each species and water potential treatment, arranged in a completely randomised design. De-ionised water with adequate moisture was considered as absence of water stress for comparisons. Germination was recorded at weekly intervals for four weeks.

Water Potential and Temperature

The experiment was similar to the above one, but with three temperature regimes of 15/10, 20/10 and 30/20^{O}C and water potentials of -0.1, -0.5 and -1.0 MPa along with control. The 12 weed species with 10 seeds per Petri dish, replicated four times were arranged in a complete random design. After adding 7 ml of PEG solution or de-ionised water (check), the Petri dishes were shifted to growth cabinets with set temperatures. Germination was recorded at weekly interval for four weeks.

Statistical Analysis

All the experiments were repeated under similar conditions at least two times to guarantee the reliability of the results. The data from two experiments had similar trends, it was pooled for analysis. Analysis of variance was performed for all experiments for both original and arcsin transformed data. Data were subjected to One-Way ANOVA for comparing means of treatment factors and weed species using SPSS.

RESULTS AND DISCUSSION

Effect of Osmotic Potential on Germination

Decreasing water potential from -0.1 to -0.2, -0.4 and -0.8 MPa decreased the germination of weed species by 12, 32, 75 and 96%, respectively, over control when data were averaged over species (Figs. 1 and 2). No germination was recorded at -1.2 MPa osmotic potential in any of the test species. Among the weed species, effect of decreased water potential was lower on the germination of Florida beggarweed and tall morningglory compared to common ragweed, Brazil pusley, strangler vine and redroot pigweed.

A mild osmotic stress of -0.1 or -0.2 MPa had no effect on the germination of tall morningglory, but germination was significantly reduced at -0.4 MPa and

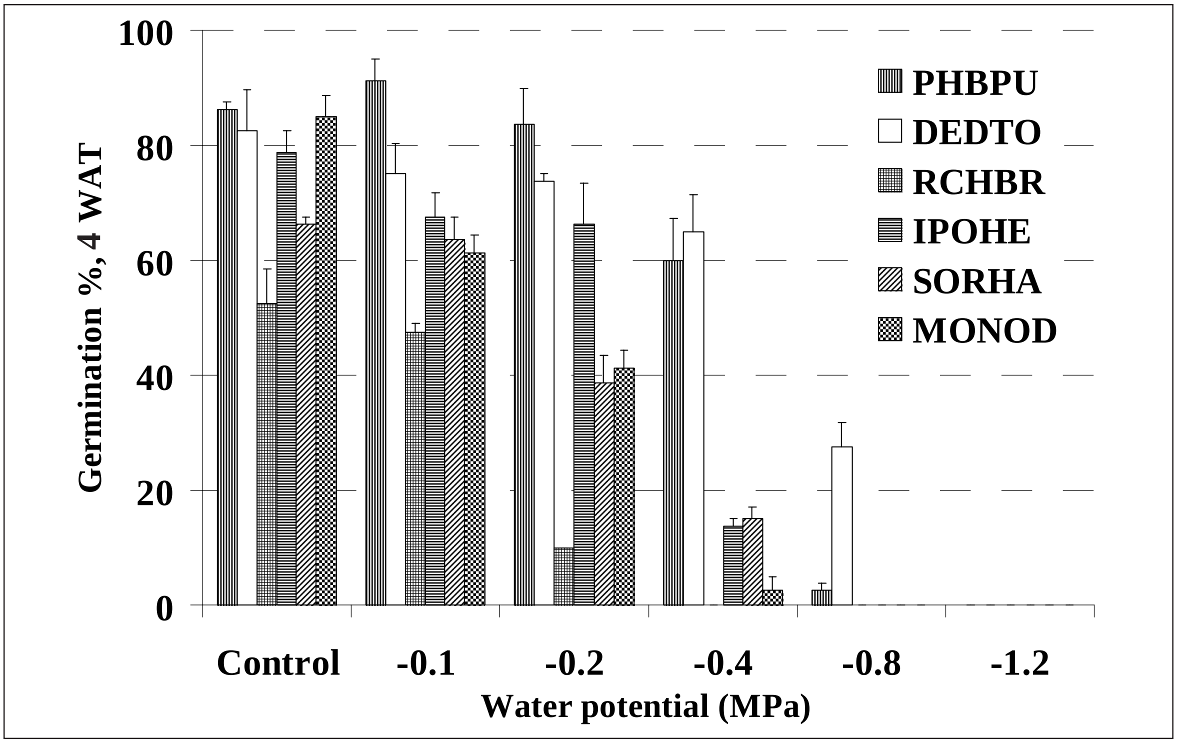

Fig. 1. Effect of water potential on the germination of tall morningglory (PHBPU), Florida beggarweed (DEDTO), Brazil pusley (RCHBR), ivyleaf morningglory (IPOHE), Johnsongrass (SORHA) and strangler vine (MONOD). Bars indicate standard error of means (SEm).

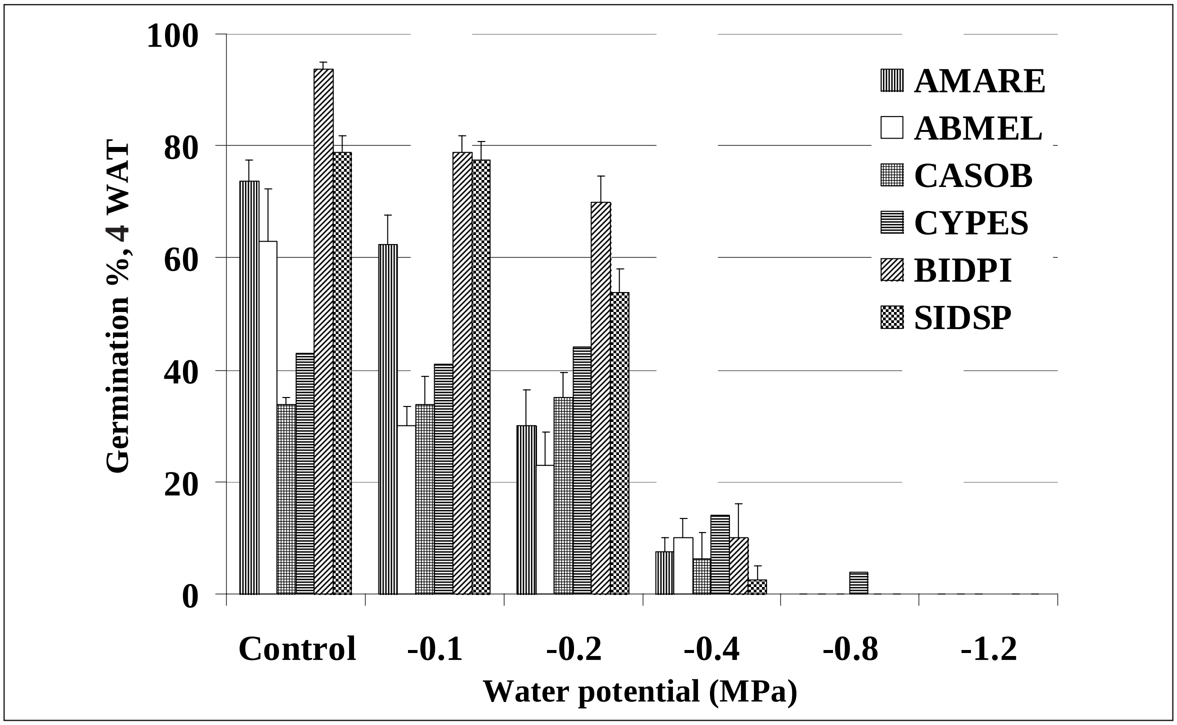

Fig. 2. Effect of water potential on the germination of redroot pigweed (AMARE), common ragweed (AMBEL), sicklepod (CASOB), yellow nutsedge (CYPES), hairy beggarticks (BIDPI) and prickly sida (SIDSP). Bars indicate standard error of means (SEm).

less than 3% seed germinated at -0.8 MPa water potential (Fig. 1). Florida beggarweed was more tolerant to water stress as water potential of -0.4 MPa had no significant reduction in its germination; however, -0.8 MPa water potential reduced germination by 67%, and no germination was recorded at -1.2 MPa (Fig. 1). While decreasing the water potential from -0.1 to -0.2 MPa resulted in 81% reduction in the germination of Brazil pusley compared to no water stress (Fig. 1). Further decrease in water potential (-0.4 MPa) resulted in complete inhibition of Brazil pusley seed germination. Ivyleaf morningglory was less affected by water stress than Brazil pusley as it required -0.4 MPa water potential to provide similar reduction in germination of ivyleaf morningglory as was observed with Brazil pusley at -0.2 MPa (Fig. 1). Germination of Johnsongrass was significantly reduced at -0.2 MPa and only 23% seed germinated at -0.4 MPa (Fig. 1). Similarly, strangler vine was sensitive to water stress as germination was reduced by 28, 52 and 97 % at -0.1, -0.2 and -0.4 MPa water potential compared to control. No germination of strangler vine was observed at -0.8 MPa (Fig. 1).

Germination of redroot pigweed was significantly decreased at -0.1 MPa and a reduction of 59 and 89% was recorded at -0.2 and -0.4 MPa water potential, respectively (Fig. 2). No germination was recorded when the osmotic potential was decreased beyond -0.4 MPa. Common ragweed germination was decreased by >50% at -0.1 MPa water potential compared to control; however, germination was similar between -0.2 and -0.4 MPa, but further increasing water stress (-0.8 MPa) caused 84% reduction in germination (Fig. 2). Sicklepod could tolerate osmotic stress of -0.2 MPa without any reduction in its germination, but increasing water stress to -0.4 MPa resulted in 80% inhibition in germination and no germination was recorded at -0.8 MPa water potential. Hairy beggarticks germination was reduced by 16 and 26%, respectively at -0.1 and -0.2 MPa water potential over control and further stress of -0.4 MPa caused 89% reduction in its germination (Fig. 2). A water potential of -0.1 had no effect on the germination of prickly sida, but further lowering the water potential to -0.2 and -0.4 MPa registered 32 and 97% reduction in germination (Fig. 2). Yellow nutsedge was more tolerant to water stress than other species as germination was similar to no stress at -0.2 MPa and 4% tubers were able to germinate at -0.8 MPa, which was not observed in any other test species (Fig. 2).

Decreasing water potential delayed the germination and complete inhibition was recorded at -0.8 MPa, except tall morningglory, yellow nutsedge and Florida beggarweed (Tables 1a and b). Water stress of -0.1 and -0.2 MPa delayed the germination of

Table 1a. Effect of osmotic potential and duration on per cent weed seed germination*

Species	Duration (DAT)	Control	-0.1 MPa	-0.2 MPa	-0.4 MPa	-0.8 MPa	-1.2 MPa
PHBPU	7	85^{a}	91^{a}	79^{b}	41^{c}	3^{d}	0^{d}
	14	85^{a}	91^{a}	83^{a}	58^{b}	3^{d}	0^{d}
	21	85^{a}	91^{a}	84^{a}	60^{b}	3^{d}	0^{d}
DEDTO	7	81^{ab}	65^{abc}	71^{ab}	50^{c}	19^{d}	0^{e}
	14	81^{ab}	71^{ab}	74^{ab}	59b^{c}	21^{d}	0^{e}
	21	83^{a}	75^{ab}	74^{ab}	65^{abc}	28^{d}	0^{e}
RCHBR	7	9^{c}	5^{c}	0^{c}	0^{c}	0^{c}	0^{c}
	14	46^{a}	30^{b}	4^{c}	0^{c}	0^{c}	0^{c}
	21	53^{a}	48^{a}	10^{c}	0^{c}	0^{c}	0^{c}
IPOHE	7	79^{a}	68^{ab}	56^{b}	6^{c}	0^{c}	0^{c}
	14	79^{a}	70^{ab}	60^{b}	11^{c}	0^{c}	0^{c}
	21	79^{a}	70^{ab}	66^{ab}	14^{c}	0^{c}	0^{c}
SORHA	7	45^{bc}	29^{d}	16^{e}	4^{e}	0^{e}	0^{e}
	14	56^{ab}	50^{bc}	31^{d}	8^{e}	0^{e}	0^{e}
	21	66^{a}	66^{a}	31^{cd}	15^{e}	0^{e}	0^{e}
MONOD	7	29^{d}	9^{e}	4^{e}	0^{e}	0^{e}	0^{e}
	14	80^{a}	40^{c}	29^{d}	3^{e}	0^{e}	0^{e}
	21	85^{a}	61^{b}	41^{c}	3^{e}	0^{e}	0^{e}

*Means followed by same letter within species do not significantly differ using Student-Newman-Keuls (P=0.5). DAT=Days after transplanting, PHBPU=Tall morningglory, DEDTO=Florida beggarweed, RCHBR=Brazil pusley, IPOHE=Ivyleaf morningglory, SORHA=Johnsongrass, and MONOD=Strangler vine.

Table 1b. Effect of osmotic potential and duration on per cent weed seed germination*

Species	Duration (DAT)	Control	-0.1 MPa	-0.2 MPa	-0.4 MPa	-0.8 MPa	-1.2 MPa
AMARE	7	34[d]	28[d]	28[d]	8[e]	0[e]	0[e]
	14	48[c]	38[cd]	30[d]	8[e]	0[e]	0[e]
	21	74[a]	63[b]	30[d]	8[e]	0[e]	0[e]
AMBEL	7	34[c]	16[d-g]	19[c-f]	5[fg]	0[g]	0[g]
	14	51[b]	24[cde]	20[c-f]	10[efg]	0[g]	0[g]
	21	63[a]	30[c-d]	23[cde]	10[efg]	0[g]	0[g]
CASOB	7	33[a]	25[a]	29[a]	6[b]	0[b]	0[b]
	14	33[a]	29[a]	33[a]	6[b]	0[b]	0[b]
	21	34[a]	34[a]	35[a]	6[b]	0[b]	0[b]
BIDPI	7	28[e]	21[ef]	10[fg]	6[g]	0[g]	0[g]
	14	88[ab]	48[d]	49[d]	10[fg]	0[g]	0[g]
	21	94[a]	79[bc]	70[c]	10[fg]	0[g]	0[g]
SIDSP	7	79[a]	45[b]	24[c]	1[d]	0[d]	0[d]
	14	79[a]	71[a]	50[b]	1[d]	0[d]	0[d]
	21	79[a]	78[a]	54[b]	3[d]	0[d]	0[d]
CYPES	7	33[ab]	26[b]	29[b]	11[cd]	0[d]	0[d]
	14	38[ab]	36[ab]	41[a]	14[c]	4[cd]	0[d]
	21	43[a]	41[a]	44[a]	14[c]	4[cd]	0[d]

*Means followed by same letter within species do not significantly differ using Student-Newman-Keuls (P=0.5). DAT=Days after transplanting, AMARE=Redroot pigweed, AMBEL=Common ragweed, CASOB=Sicklepod, BIDPI=Hairy beggarticks, SIDSP=Prickly sida and CYPES=Yellow nutsedge.

Johnsongrass by one and two weeks, respectively. Germination of tall morningglory, Florida beggarweed, ivyleaf morningglory, prickly sida and sicklepod was faster and within 2-3 days maximum germination was recorded under control treatment (Tables 1a and b). Water potential of -0.2 MPa delayed the germination of tall and ivyleaf morningglory, Johnsongrass, strangler vine, hairy beggarticks, yellow nutsedge and prickly sida by 1-2 weeks, though still lower than under no stress. Germination was slow in Brazil pusley, strangler vine and hairy beggarticks and required more than seven days even without water stress to germinate fully. Delayed germination under increased water stress of many weed species may be characterized by decreased water uptake with varying osmotic potential levels thus affecting the imbibition process. Germination and growth were affected with decreasing osmotic potentials for most of the weed seeds.

Delayed emergence of yellow nutsedge was observed under water stress conditions in pots buried in fields in California and Arizona (Wilen *et al.*, 1996). Tubers subjected to the dry treatment needed a higher number of accumulated degree-day units before emergence occurred and had fewer emerged shoots as compared to the wet treatment. Increasing osmotic stress has been found to delay or inhibit the germination of annual, ivy and small flower morningglory (Crowley and Buchanan, 1980). Increased osmotic stress from -0.08 to -0.8 MPa decreased germination of bigfoot morningglory linearly from 90 to 0% (Horak and Wax, 1991). Hoveland and Buchanan (1973) reported that under artificial drought *Ipomoea lacunosa* was the most tolerant weed species followed by *Sida spinosa* and *Cassia obtusifolia*. Variations in germination with respect to differential osmotic potential have been reported with different weed species (Cardwell, 1984; MacDonald *et al.*, 1992; Smith *et al.*, 1992; Brecke, 1995; Mollin *et al.*, 1997).

There is large variation in the germination of weed species under different moisture regimes. Germination of *Cyperus iria* was inhibited by 50% at 0.5 MPa, whereas it required only 0.1 MPa water potential for similar reduction in *C. difformis* (Chauhan and Johnson, 2010). Similarly, germination of *Corchorus olitorius* and *Mimosa invisa* was inhibited by 50% at -0.9 MPa water potential, but similar reduction in germination of *Leptochloa chinensis* was observed at -0.1 MPa. Water stress below -0.2 MPa reduced seed germination of *Urena lobata* (Wang *et al.*, 2009). Germination of Texasweed (*Caperonia palustris*) was observed at -0.8 MPa water potential though it decreased by 84% compared to no stress (Koger *et al*., 2004). Reddy and Singh (1992) reported that osmotic stress up to -0.1 MPa had little effect on germination of *B. pilosa*, but <3% of the seed germinated when stress was increased to -0.75 MPa.

In a hydroponic study using PEG-8000 to induce water stress on reproductive ability of downy brome (*Bromus tectorum*), it was found that severe water stress of -1.1 MPa for seven days during culm elongation or anthesis inhibited seed formation (Richardson *et al*., 1989). A mild water stress (-0.1 MPa) during anthesis or moderate water stress (-0.5 MPa) during anthesis or seed filling stage resulted in reduced seeds per panicle. Due to unsynchronous maturity of weeds compared to crops; withholding irrigation can lower the seed production of weeds with no adverse effect on crops.

Effect of Osmotic Potential and Temperature on Germination

Increasing the temperature from 15 to 20 and 30^{O}C increased germination of weed species (averaged over treatments) from 11 to 22 and 34%, respectively, when data were averaged over species (Figs. 3-8). Germination was reduced by 21, 88 and 99% at -0.1, -0.5 and -1.0 MPa osmotic potential compared to control treatments. There was no germination of any weed species, except Florida beggarweed at -1.0 MPa osmotic potential.

Increasing the temperature from 15 to 20 and 30^{O}C increased the germination of tall morningglory from 10 to 34 and 43% at -0.5 MPa osmotic potential; there was no difference in the germination at -0.1 MPa osmotic potential (85-88%) at any temperature regime, whereas maximum germination of 95% was recorded at 30^{O}C under control which was similar to lower temperatures (Fig. 3). On the other hand, germination of ivyleaf morningglory was higher at 20 (88%) than 15 (45%) or 30^{O}C (78%) with no water stress and germination significantly decreased at -0.5 MPa osmotic potential. Lowering the temperature from 20 or 30^{O}C to 15^{O}C resulted in 75% lower germination of ivyleaf morningglory at -0.1 MPa water potential (Fig. 3).

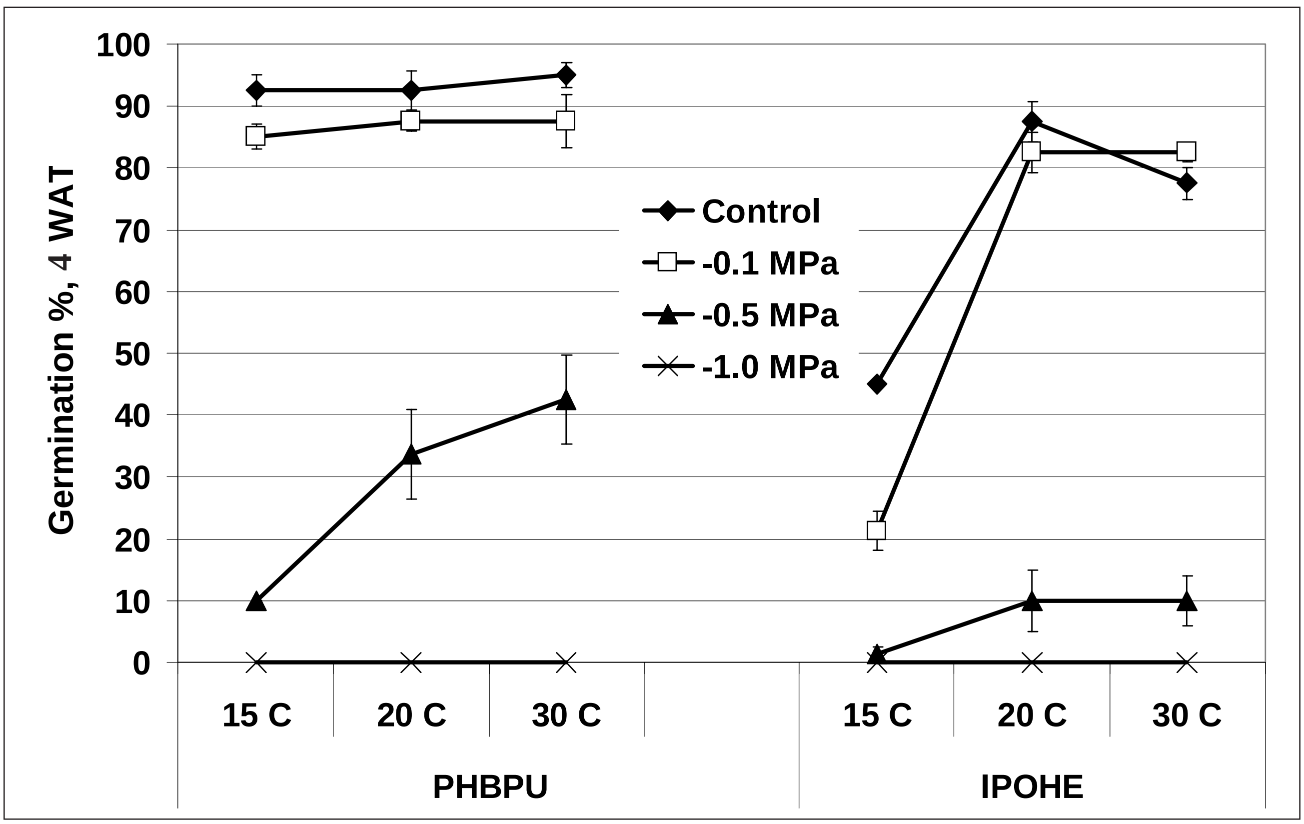

Fig. 3. Effect of temperature and water potential on germination of tall morningglory (PHBPU) and ivyleaf morningglory (IPOHE). Bars indicate standard error of means (SEm).

Increasing temperature and water stress significantly increased the germination of Florida beggarweed (Fig. 4). Germination increased from 3 to 78 and 80% with increase in temperature from 15 to 20 and 30°C. No germination was recorded at 15°C with any level of water stress, but increasing temperature from 15 to 20°C resulted in 50% germination at -0.1 MPa osmotic potential. The interaction of temperature and osmotic potential was more visible at 30°C, where germination of 78, 43 and 11% was recorded at -0.1, -0.5 and -1.0 MPa, respectively. Similar effect of increased temperature and water stress was recorded for Brazil pusley (Fig. 4); though germination was decreased significantly at -0.5 MPa and no seed germinated at -1.0 MPa osmotic potential.

Similarly, germination of Johnsongrass and strangler vine was negligible below 30°C, but increased water stress decreased germination greatly (Fig. 5). An osmotic stress of -0.1 decreased the germination of Johnsongrass and strangler vine by 49 and 37%, respectively, over no water stress at 30°C and no germination occurred with increasing water stress.

Germination of redroot pigweed was also more at 30°C compared to lower temperature and increasing water stress decreased germination by 25 and 98% at -0.1 and -0.5 MPa osmotic potential (Fig. 6). Contrarily, germination of common ragweed was more at 20 or 15°C than 30°C and reduction in germination was more with increasing water stress of -0.5 MPa at lower than higher temperature (Fig. 6). At -0.1 MPa germination of common ragweed was 17 and 29% lower at 15 and 30°C compared to 20°C.

Sicklepod germination increased with increase in temperature with no water stress; however, germination was similar between 20 and 30°C at -0.1 MPa osmotic potential and only 6% seed germinated at -0.5 MPa at 20°C (Fig. 7). Similarly, yellow nutsedge germination increased with increase in temperature from 15 to 20°C and increase in water stress (-0.5 MPa) had similar effect on germination at 20 or 30°C (Fig. 7). Significant positive correlation was observed in hairy beggarticks and prickly sida as germination increased

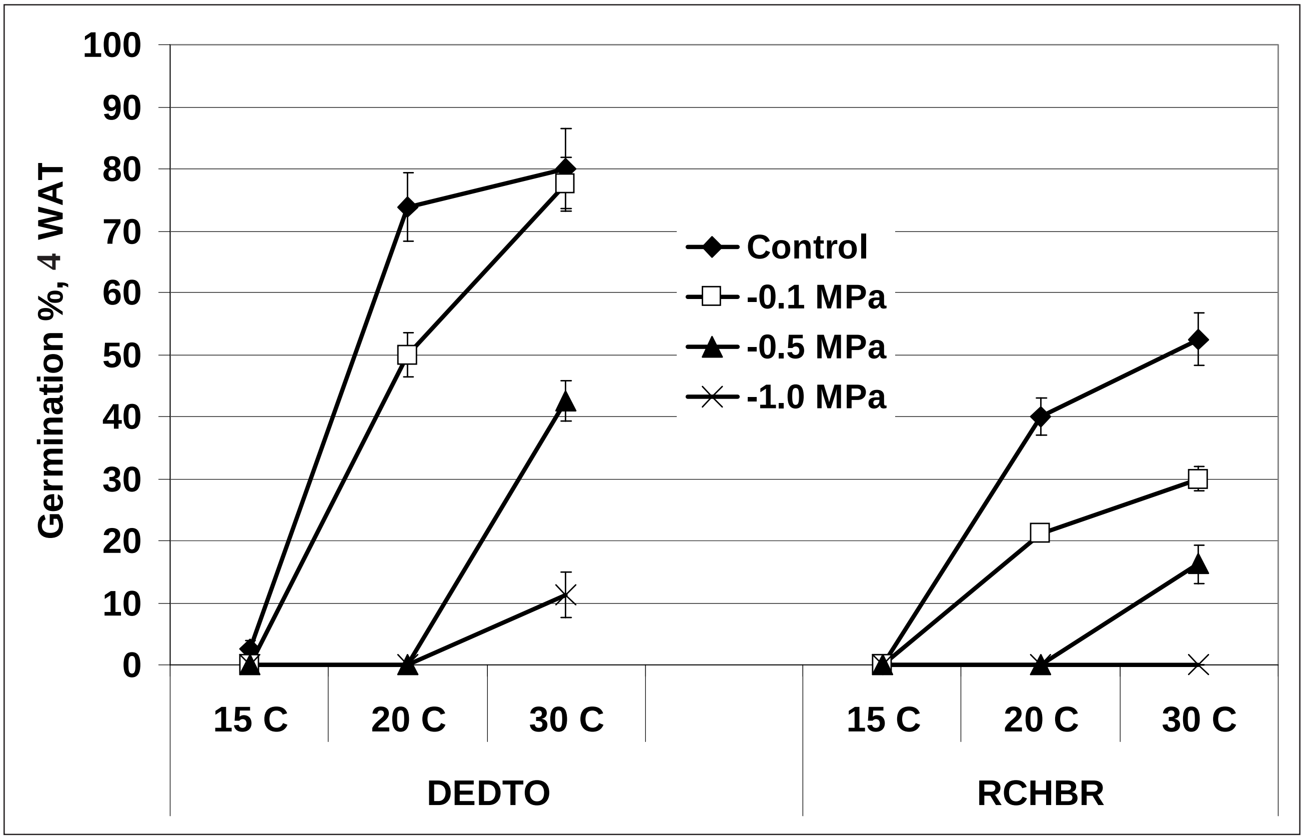

Fig. 4. Effect of temperature and water potential on germination of Florida beggarweed (DEDTO) and Brazil pusley (RCHBR). Bars indicate standard error of means (SEm).

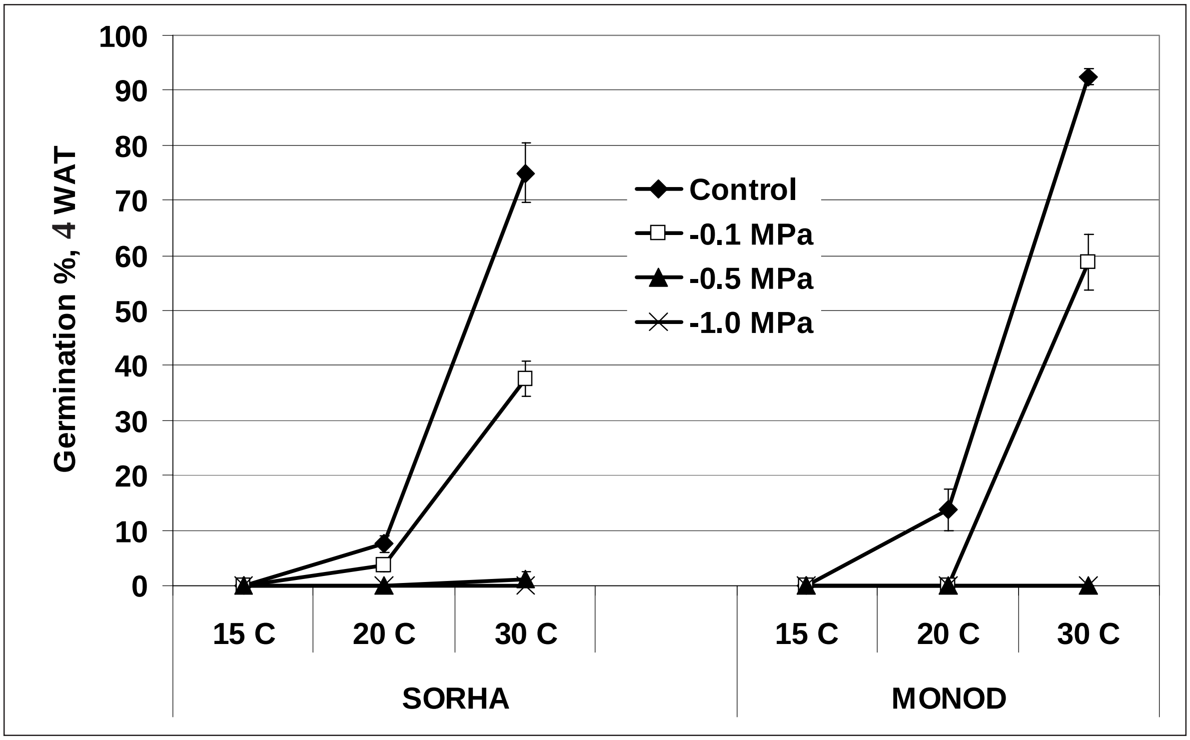

Fig. 5. Effect of temperature and water potential on germination of johnsongrass (SORHA) and strangler vine (MONOD). Bars indicate standard error of means (SEm).

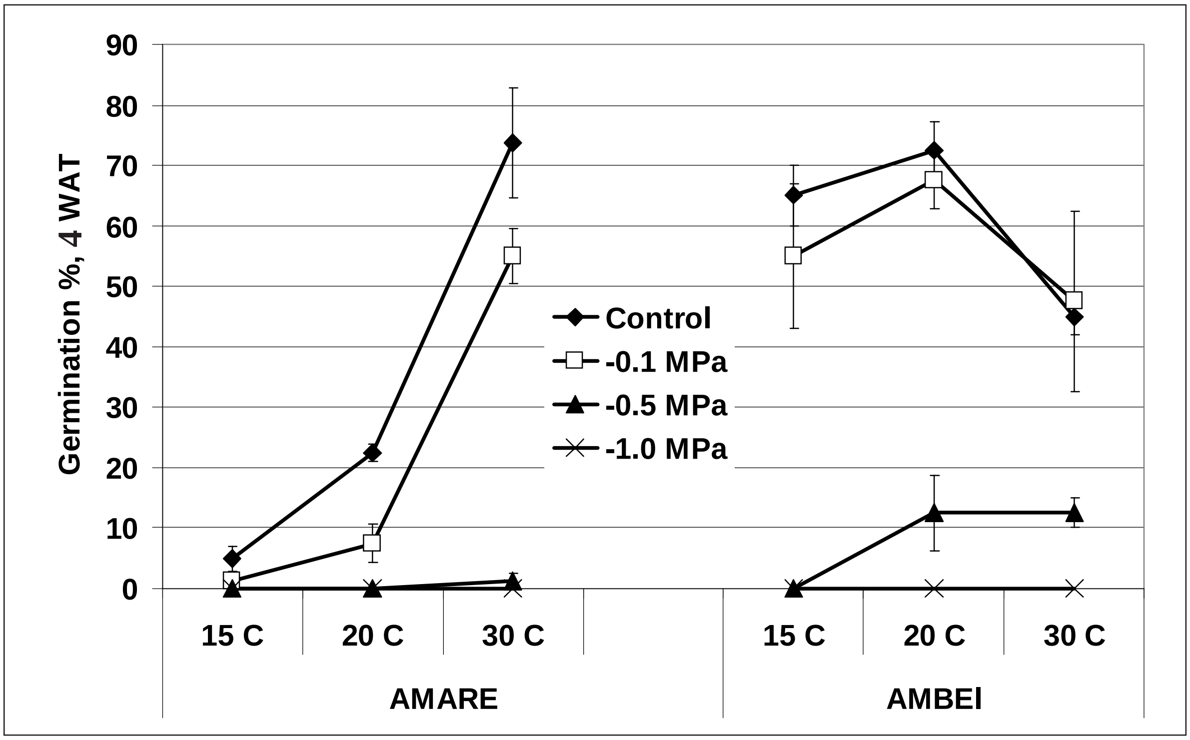

Fig. 6. Effect of temperature and water potential on germination of redroot pigweed (AMARE) and common ragweed (AMBEL). Bars indicate standard error of means (SEm).

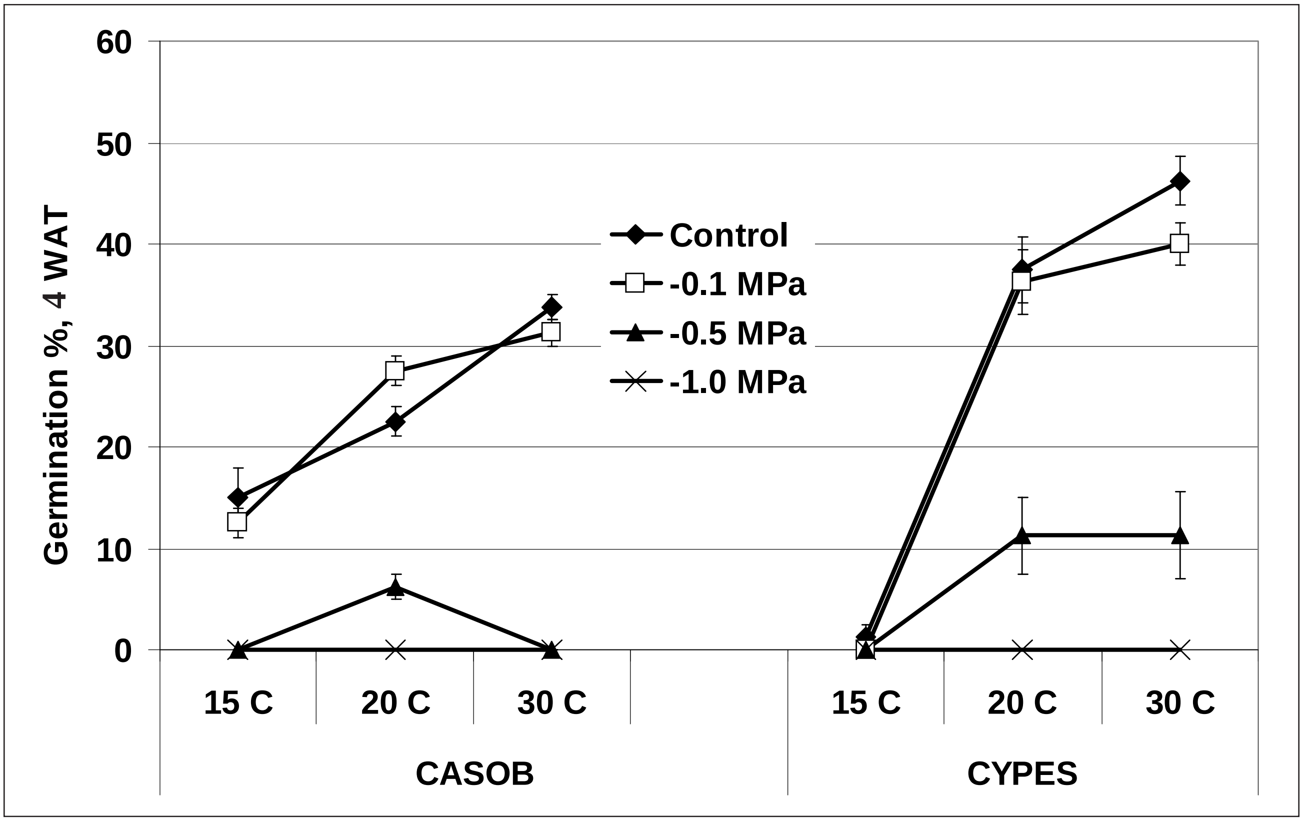

Fig. 7. Effect of temperature and water potential on germination of sicklepod (CASOB) and yellow nutsedge (CYPES). Bars indicate standard error of means (SEm).

with increase in temperature and water stress (Fig. 8). Germination of hairy beggarticks was similar at 30^{O}C between no water stress and -0.1 MPa water potential, but was 54 and 40% higher over 15 or 20^{O}C, respectively. Similarly, prickly sida germination was 66% at 30^{O}C compared to only 31% at 20^{O}C when -0.1 MPa water stress was imposed (Fig. 8). Only 3% germination of prickly sida was recorded at -0.5 MPa at 30^{O}C and no germination at lower temperatures.

Temperature plays a significant role in seedling germination at a given moisture level (Finch-Savage and Phelps, 1993). Seed must reach a specific per cent moisture before germination. Different species can reach this optimum moisture percentage at different moisture tensions in soils. At -0.4 MPa water potential, no germination of *Cassia occidentalis* occurred at 15^{O}C, whereas 15% germination occurred at 30^{O}C (Norsworthy and Oliveira, 2005). Low water potential has been found to delay the onset of seed germination, slow the rate of germination, and decrease final germination percentage (Lafond and Baker, 1986; Bradford 1990; Battaglia, 1997; Burke *et al*., 2003). One of the requirements when planting crop seed is to provide a good seed zone environment to ensure seed germination and emergence. Depth of planting is important because soil temperature and moisture availability can vary with depth and may directly influence germination and rate of emergence. Special care should be taken to provide a proper seedbed and uniform planting depths for crop seed. By identifying weaknesses in a plant's life cycle, effective management techniques can be established to reduce its emergence as well as its competitive ability. Because tillage operations influence weed seed placement within the soil profile, research evaluating weed seed emergence as influenced by depth may be helpful.

Of all the environmental factors affecting weed ecology, soil moisture and temperature are probably the most important. One of the main objectives in weed research is the enormous reservoir of viable dormant weed seeds present in the soil, which escape mechanical and chemical weed control. Since buried seeds are extremely hard to kill, efforts are directed mainly toward identifying and manipulating the environmental factors that control their germination and growth. Soil

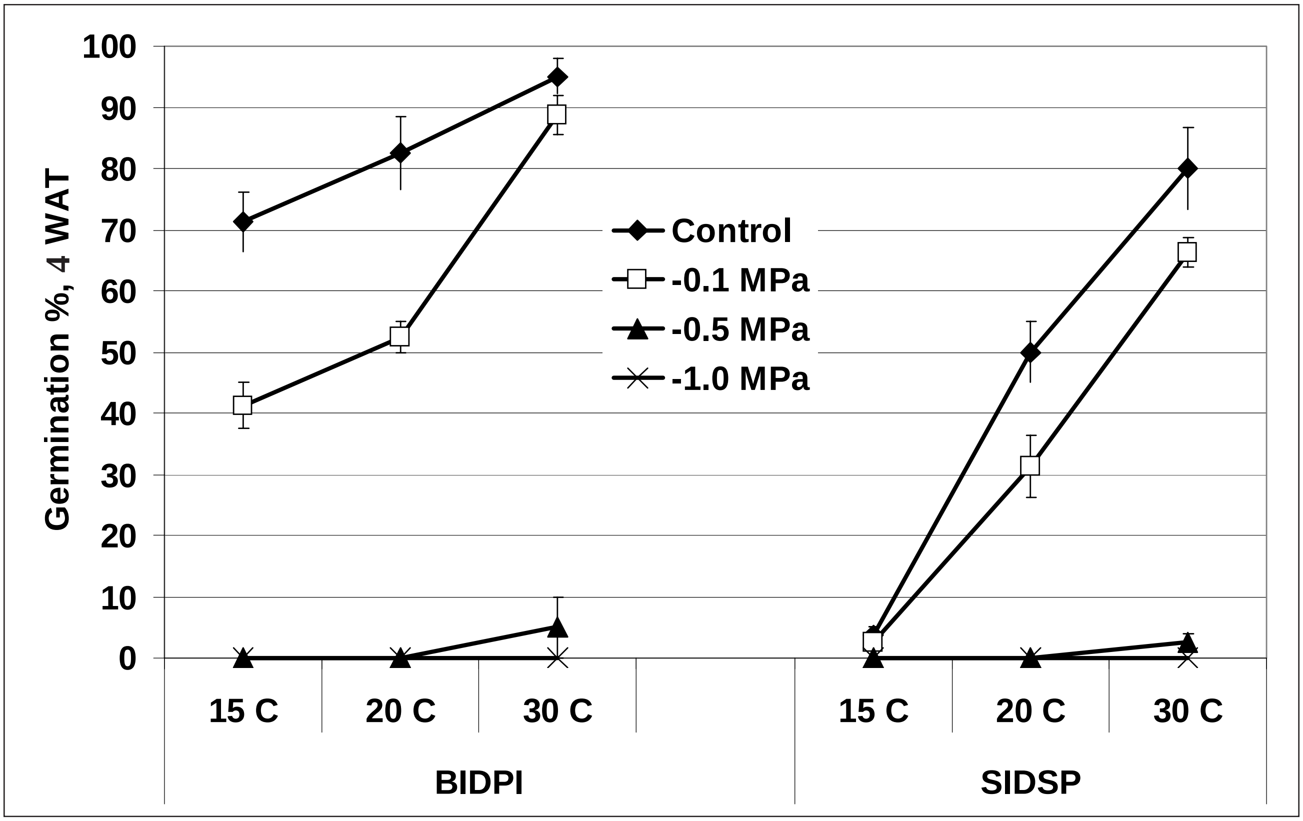

Fig. 8. Effect of temperature and water potential on germination of beggarticks (BIDPI) and prickly sida (SIDSP). Bars indicate standard error of means (SEm).

temperature and water status play key roles and their manipulation to provide a competitive edge to crops by delayed or decreased emergence and can be exploited for sustainable weed management. As there are large variations in different weed species to these environmental factors, an understanding of the weed seed bank of the dominant species in the field can easily be exploited in designing the most effective management strategy against the target weed species. Interactions of temperature and moisture to stimulate breaking weed dormancy and enhance germination and then killing the seedling during field preparations or non-selective and non-residual herbicides can exhaust soil seed bank and lower crop-weed competition. Conversely these interactions can also be used to delay or reduce weed seed germination to provide the crop a head start and late emerging weeds can be smothered by the established crop canopy.

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