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Effect of Temperature, Light and pH on Germination of Twelve Weed Species

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ABSTRACT

Growth cabinet studies were conducted on the effect of temperature, pH and light exposure on seed germination of Brazil pusley, common ragweed, Florida beggarweed, hairy beggarticks, ivyleaf morningglory, Johnson grass, prickly sida, redroot pigweed, sicklepod, strangler vine, tall morningglory and yellow nutsedge. When averaged over all species and temperatures, highest weed seed germination was recorded in the temperature regime of 25 to 35^{O}C, maximum being at 30^{O}C. Lower temperature of 15^{O}C inhibited germination of Johnson grass, Brazil pusley, Florida beggarweed, redroot pigweed, prickly sida and yellow nutsedge. Germination of common ragweed and ivyleaf morningglory was highest at 20^{O}C, and significantly decreased above 35^{O}C. Higher temperatures (30 to 40^{O}C) were less inhibitory to germination of redroot pigweed, Johnson grass, Florida beggarweed, prickly sida and yellow nutsedge compared to other weed species. Tall morningglory and hairy beggarticks had high germination rates from 15 to 35^{O}C. Germination of prickly sida and Florida beggarweed was highest between 25 to 40^{O}C and sicklepod from 20 to 40^{O}C. Strangler vine germination was highest at 30^{O}C and decreased significantly with any increase or decrease in temperature. No weed seed germinated at pH 3, except yellow nutsedge. A pH range of 5 to 11 had no adverse effect on germination, when data were averaged over species. Germination of prickly sida was highest at pH 9 and any increase or decrease in pH resulted in reduced germination. Yellow nutsedge seed germinated 14% at pH 3 compared to 47% at pH 7. Germination was not inhibited for any test species in dark, except Brazil pusley. After 168 h, germination of Brazil pusley ranged from 2 to 10% with light exposure of 0 and 16 h, respectively, before placing them in dark. Under alternate light and darkness cycle of 12 h, germination of Brazil pusley increased to 59%. Other than Brazil pusley no other species exhibited the photoblastic effect.

Key words : Biology, management, dormancy, germination, temperature, pH, light

INTRODUCTION

Time of weed emergence relative to crop emergence largely affects crop-weed competition and is critical to avoid yield losses. The interactions of environmental conditions and the crop physiological stage of seed have been shown to regulate their germination in the soil (Taylorson, 1970, 1987; Moore *et al*., 1994). Weed seed germination as affected by microsite, physical stimuli, and environmental factors has been the subject of many laboratory and greenhouse investigations (Singh and Acchireddy, 1984; Gealy *et al*., 1985; Shaw *et al*., 1987). Germination of some crop seed is affected with moisture tensions of -0.05 to -0.3 MPa (Cardwell, 1984), whereas wild poinsettia (*Euphorbia heterophylla*) germination was not reduced until -0.8 MPa soil moisture (Brecke, 1995) suggesting higher ability of weeds for survival under adverse conditions. An adaptation to maximize survival of annual weed species is seed germination despite variable environmental conditions that may not reflect optimum conditions (Baskin and Baskin, 1989). Low winter temperature is known to stimulate the loss of primary dormancy for most summer annuals. Weed seeds exposed to low temperature will not germinate until ecophysiological factors including light, temperature, moisture and oxygen are adequate for germination (Egley and Duke, 1985). Temperature and light have significant effect on weed seed germination by regulating secondary dormancy of annual weeds (Taylorson, 1972, 1982; Khan and Karssen, 1980).

Temperature has a significant effect on the adaptability of weed species. Yellow nutsedge (*Cyperus esculentus*) is more widespread than purple nutsedge (*C. rotundus*) in the US, because the latter can't withstand freezing temperature (Stoller, 1973). Under laboratory conditions <10% of purple nutsedge tubers survived at 2^{O}C for 12 weeks, whereas >95 of yellow nutsedge tubers survived this temperature. An exposure of 4 h to -2^{O}C killed 50% of purple nutsedge tubers, whereas -6.5^{O}C was required for similar mortality of

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yellow nutsedge tubers. Occurrence of purple nutsedge is restricted to regions of high soil temperature, whereas yellow nutsedge is distributed in regions where the soil temperatures often fall below freezing. Rubin and Benjamin (1984) reported that tubers of yellow nutsedge could survive temperature as high as 80^{O}C for 30 min. Thus, temperature plays a significant role on the preponderance of weed species in different geographical regions.

Seed of some weed species can emerge from a wide range of planting depths (Singh and Acchireddy, 1984; Wilson, 1979), whereas seeds of others must be close to surface (Balyan and Bhan, 1986; Shaw *et al*., 1987); both situations are influenced by several interrelated factors of light, temperature, moisture and other soil physical conditions. In addition pH (Wilson, 1979; Sorters and Murray, 1981; Shaw *et al*., 1987) and temperature (Wilson, 1979; Gealy *et al*., 1985; Hemmat *et al*., 1985) requirements for germination significantly vary according to weed species.

Soil temperature is a major environmental factor that influences weed seed germination and emergence. The rate of emergence of weeds is closely correlated with soil temperatures (Cardwell, 1984). Temperature regulates germination by removing dormancy (Taylorson and McWhorter, 1969; Wagenvoort and Bierhuizen, 1977; Benech-Arnold *et al*., 1988, 1990) and by determining the germination rate of seed whose dormancy has been broken (Bewley and Black, 1982). Some seeds possess specific temperature regulated dormancy mechanisms, whereas other seeds germinate over a wide range of temperature (Mayer and Poljakoff-Mayber, 1982). Temperature strongly influences the length of time between the start of imbibition and the beginning of germination.

Light also plays a significant role in initiating germination of many weed seeds. Freshly harvested seed of *Portulaca oleracea* (purslane) did not germinate in darkness between 10 to 40^{O}C; however, seed stored for one year had temperature dependant dark germination (Singh, 1973). Enhanced germination of *Parthenium hysterophorus* was reported under dark conditions (Dhawan and Dhawan, 1994). Requirement of light for germination varies significantly with weed species and even a short light exposure can break seed dormancy impacting germination (Andersson *et al*., 1997; Milberg and Andersson, 1998). Weed species whose germination is triggered by light exposure can be controlled by limiting light exposure by cultural methods and use of various mulches (Buhler *et al*., 1997; Botto *et al*., 1998; Kegode *et al*., 1998; Zimdahl, 1999).

Parochetti (1980) suggested modification of soil pH and organic matter levels instead of crop rotations to effectively control redroot pigweed, yellow nutsedge and other problem weeds. Soil pH could also influence the competitive ability of weed species. Previous reports suggest that the relative competitive ability of redroot pigweed was greater at pH 7.5 compared to 5.5 (Anonymous, 1980). Composition of weed flora is greatly influenced by pH of the field and any alteration may change the dominance of weed species infesting crop fields.

Information on germination, emergence, growth and seed production could be used to help model weed seed bank dynamics, thus helping the successful forecasting of germination trends and rational weed control in the agroecosystem (Aim *et al*., 1993; Forcella, 1993).

The ability to characterize germination and emergence due to various environmental factors should improve our understanding of weed seed dynamics in soil and enhance our weed management capabilities. Due to rapid rate of evolution of resistant weed biotypes to herbicides of different chemistries, it is essential to understand the biology and ecology of weeds for effective weed management using an integrated approach. Research on ecological approaches for effective weed control is crucial and must be integrated with available control strategies.

The main objective of the present work was to determine the effect of environmental factors (temperature, pH and light) on germination of 12 weed species which are serious weeds of many crops including citrus.

MATERIALS AND METHODS

Source and Storage of Weed Seeds

Seed of Brazil pusley were collected from local citrus orchards and common ragweed seeds were purchased a month prior to initiating germination study. All other weed seeds were more than 5-year old and had no dormancy. Test species seeds were either purchased from Valley Seed Service, P. O. Box 9335, Fresno, CA 93791 or collected locally and stored in a refrigerator at 5^{O}C.

Weed Species

Seeds of common ragweed, *Ambrosia artemisiifolia* L. [AMBEL]; Brazil pusley, *Richardia brasiliensis* (Moq.) [RCHBR]; Florida beggarweed, *Desmodium tortuosum* (Sw.) DC. [DEDTO]; ivyleaf morningglory, *Ipomoea hederacea* (L.) Jacq. [IPOHE]; hairy beggarticks, *Bidens pilosa* L. [BIDPI]; Johnson grass, *Sorghum halepense* (L.) Pers. [SORHA]; redroot pigweed, *Amaranthus retroflexus* L. [AMARE]; strangler vine, *Morrenia odorata* (Hook & Am.) Lindl. [MONOD]; sicklepod, *Cassia obtusifolia* L. [CASOB]; prickly sida, *Sida spinosa* L. [SIDSP]; tall morningglory, *Ipomoea purpurea* (L.) Roth. [PHBPU]; and yellow nutsedge, *Cyperus esculentus* L. [CYPES] were used in the present study.

Experimental Conditions

All germination studies were carried out in growth cabinets (Percival Scientific, Inc. Model : E-36L, 1805 East 4th Street, Boone, IA 50036) under controlled environmental conditions. Four growth cabinets were used in these studies set at variable temperatures at 70±5% relative humidity (RH) with 12 h photoperiod (day/night) and 255 µMol/m^2/s PPFD. There were four replications for each treatment arranged in a completely randomized design, and the study was repeated under similar conditions four weeks apart. Germination of weed seed was counted and germinated seeds were removed at weekly intervals for three weeks. Emergence of the radicle of 1 mm or more in length was considered as germinated seed.

Temperature Studies

For each treatment, 10 seeds of each weed species were placed in 90 mm diameter Petri dish lined with double layered Whatman No. 4 filter paper. After adding 7 ml de-ionised water, the Petri dishes were placed in growth cabinets, already set to 15/10, 20/10, 25/15, 30/20, 35/25, 40/30 and 45/35^{O}C day/night temperature cycle. Petri dishes were watered as and when required. The experiment was repeated twice under similar conditions.

Effect of pH on Germination

Buffered solutions with pH levels of 3 and 5 were prepared by using citric acid and pH of 7, 9 and 11 by using potassium hydroxide pellets to study the effect of pH on germination of 12 weed species. Ten seeds of each weed species were planted in double lined Whatman No. 4 filter paper in Petri dishes. A 7 ml pH solution was added to each Petri dishe and shifted to growth cabinets maintained at 30/20^{O}C (day/night) temperature. Petri dishes were watered as and when required with freshly prepared pH solutions. The experiment was repeated thrice under similar conditions for confirmation of pH effects on germination.

Effect of Light Exposure on Germination

Seeds of 12 weed species were exposed to light for 0, 0.5, 1, 2, 4, 8 and 16 h after adding 7 ml of water to Petri dishes with 10 seeds of each species. Petri dishes were wrapped in double layers of aluminum foil and moved to growth cabinets set at 30/20°C temperature. Comparisons were made with uncovered seeds (Petri dishes) with a 12 h photoperiod (day/night). Germination was recorded after 7-10 days of incubation. The experiment was repeated three times under similar conditions to confirm the results.

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/three experiments had similar trends, it was pooled for analysis. Analysis of variance was performed for all experiments for both original and arcsin transformed data using SPSS [Statistical Package for Social Sciences (SPSS) Version 10, SPSS Inc., 233 S. Wacker Drive, 11th Floor, Chicago, IL 60606-6307, United States]. Data were subjected to one-way ANOVA for comparing means of treatment factors and weed species.

RESULTS AND DISCUSSION

Effect of Temperature on Germination

Maximum germination of 74% was observed at alternating temperature of 30/20^{O}C when data were averaged for weed species and temperatures and was significantly better than 65% germination observed at 25/15 and 35/25^{O}C (Figs. 1 and 2). There was a significant decrease in germination of weed species with any increase or decrease in day temperature from 30^{O}C. Minimum germination of 27% was recorded for both 15/10 or 45/30^{O}C temperatures in a 12 h photoperiod. Among weed species, germination was highest in hairy beggarticks and tall morningglory followed by redroot pigweed, ivy leaf morningglory and Florida beggarweed, when data were averaged over temperatures.

Annual/tall morningglory had more than 90% germination on a wide alternating temperature range of 15 to 30^{O}C, but decreased significantly after 35^{O}C and only 9% germination was recorded at 45^{O}C (Fig. 1). Germination was statistically similar between 15 to 35^{O}C temperatures, but decreased by 59 and 91%, respectively, at 40 and 45^{O}C compared to 30^{O}C (Fig. 1).

Higher temperature was less inhibitory to Florida beggarweed than lower temperature as 59% seed germinated at 45^{O}C compared to only 1% germination at 15^{O}C (Fig. 1). Higher germination (>75%) of beggarweed was recorded between 25 to 40^{O}C, which was significantly better than 20 or 45^{O}C. At 30^{O}C germination of Florida beggarweed was highest (81.25%) and increase or decrease in temperature to 45 or 20^{O}C resulted in 28 and 18% lower germination, respectively, compared to 30^{O}C.

No germination of Brazil pusley was recorded at 15^{O}C; higher germination on the other hand was less inhibitory (Fig. 1). Highest germination of 70% was recorded at 30^{O}C followed by 58% at 25^{O}C. Further increase or decrease in temperature resulted in significantly lower germination of Brazil pusley.

Ivyleaf morningglory germinated better (90%) at 20^{O}C than 15^{O}C; germination was significantly decreased at 40^{O}C and only 6% seed could germinate at 45^{O}C (Fig. 1). Germination was decreased by 13% at 35 than 20^{O}C, but was statistically similar. Lower temperature of 15^{O}C was less inhibitory as 58% seed

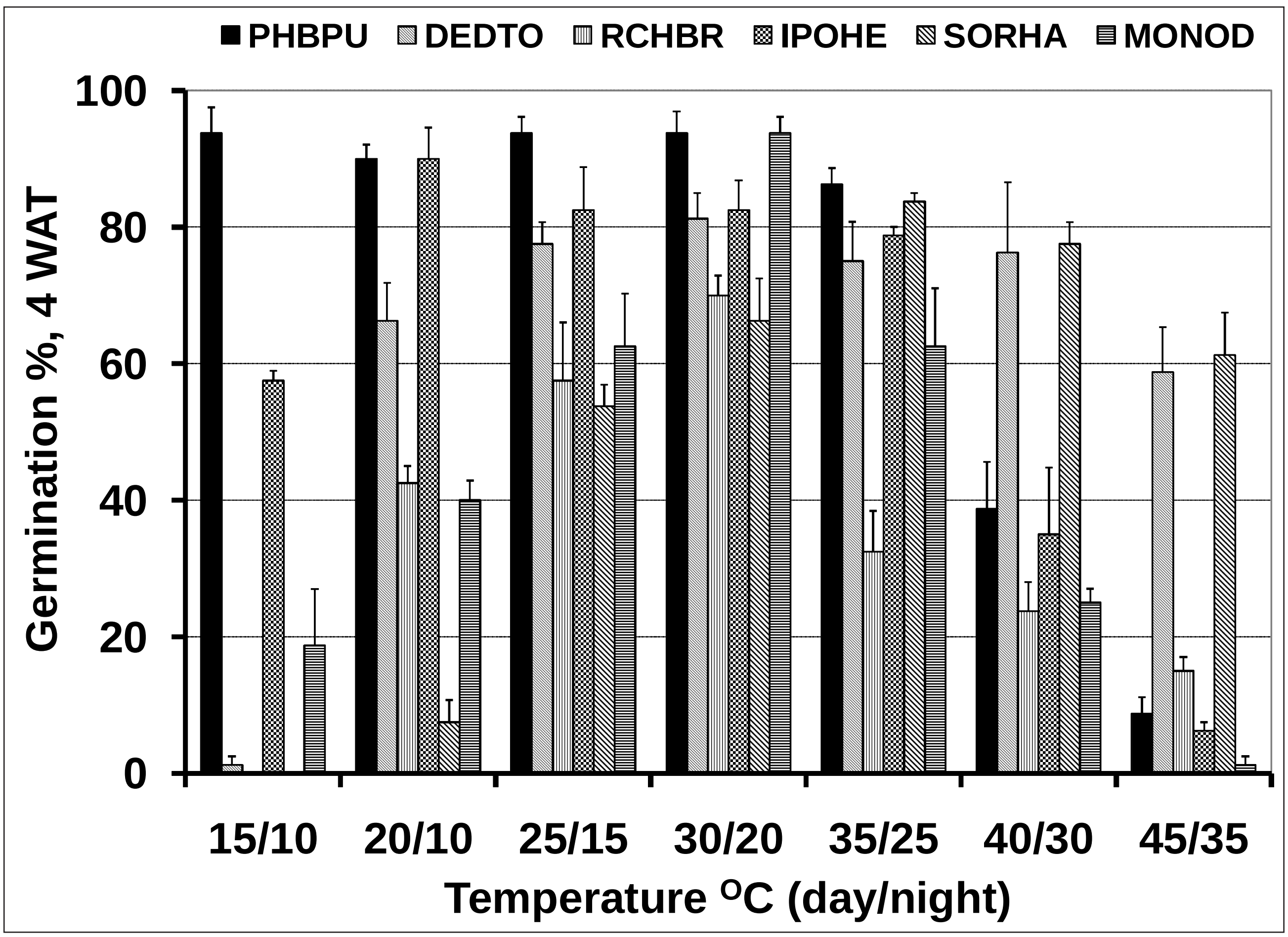

Fig. 1. Effect of temperature on the germination of tall morningglory (PHBPU), Florida beggarweed (DEDTO), Brazil pusley (RCHBR), ivyleaf morningglory (IPOHE), Johnson grass (SORHA) and strangler vine (MONOD). Bars indicate standard error of means.

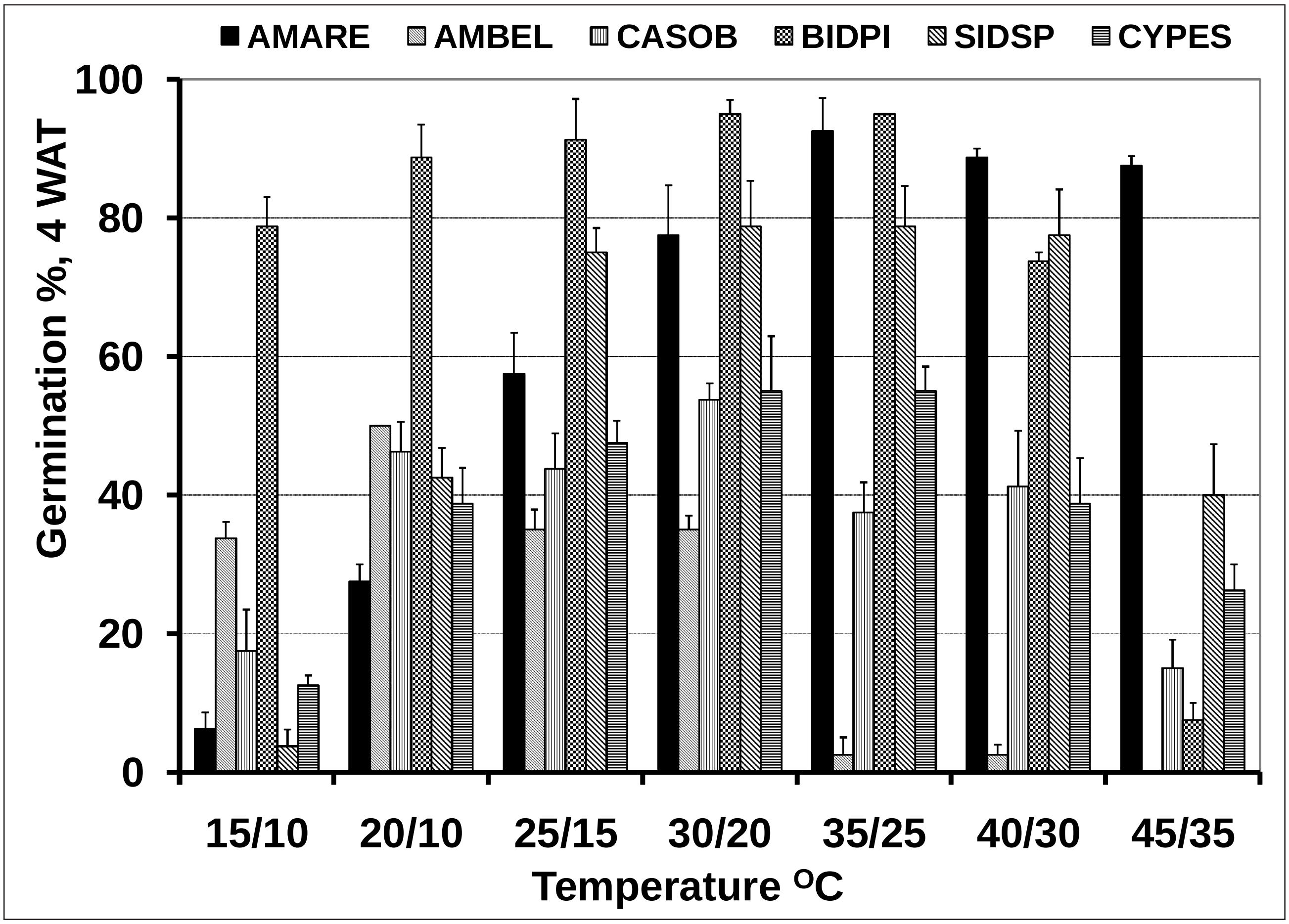

Fig. 2. Effect of temperature on germination of pigweed redroot (AMARE), common ragweed (AMBEL), sicklepod (CASOB), hairy beggarticks (BIDPI), prickly sida (SIDSP) and yellow nutsedge (CYPES). Bars indicate standard error of means.

germinated compared to 35 and 6% at 40 and 45°C, respectively (Fig. 1).

Johnson grass had no germination at 15°C temperature, but higher temperature was less inhibitory (Fig. 1). Johnson grass recorded 61% germination at 45°C compared to only 8% germination at 20°C (Fig. 1). Increase in temperature from 20°C increased the germination of Johnson grass and highest germination was recorded at 35 followed by 40°C.

A temperature of 30°C was ideal for strangler vine germination (Fig. 1). Germination was significantly decreased with any increase or decrease in temperature from 30°C. A reduction of 80 and 99% was recorded at 15 and 45°C, respectively, compared to germination at 30°C (Fig. 1).

Germination of redroot pigweed was significantly inhibited at lower than higher temperatures (Fig. 2). Only 6% seeds were able to germinate at 15°C compared to 88% at 45°C. Germination of redroot pigweed increased significantly from 6 to 28 and 58% with increase in temperature from 15 to 20 and 25°C, respectively. Highest germination of 93% was recorded at 35°C, which was similar to 30 or 45°C.

Common ragweed germinated well from 15 to 30°C, and no germination was recorded at 45°C (Fig 2). Highest germination of common ragweed was observed at 20°C which was significantly higher than 15, 25 or 30°C and reduced by 95% at 35 or 40°C compared to 20°C.

Sicklepod germination was recorded at all temperature regimes from 15 to 45°C; though germination was reduced at both the extremes (Fig. 2). A reduction of 67 and 72% in germination was recorded at 15 and 45°C, respectively, compared to the highest germination of 54% at 30°C. Germination of sicklepod was similar between temperature ranges of 20 to 40°C.

Similarly, higher germination of 74 to 95% was recorded for hairy beggarticks from 15 to 40^{O}C, but only 8% seed could germinate at 45^{O}C (Fig. 2). At 15^{O}C germination was reduced by 17% compared to 30^{O}C, it was highest among all the test species. Increase in temperature beyond 35^{O}C significantly reduced the germination of hairy beggarticks.

A temperature range of 25 to 40^{O}C was ideal for the germination of prickly sida; germination was reduced by 50% at 45 or 20^{O}C compared to 30^{O}C (Fig. 2). Germination was greatly reduced at 15^{O}C as only 4% seeds were able to germinate compared to 79% at 35^{O}C. A lower temperature of 15^{O}C was equally inhibitory to that of 45^{O}C in reducing the germination of yellow nutsedge (Fig. 2). Yellow nutsedge had significantly higher germination at 20 to 40^{O}C.

Germination of annual and ivyleaf morningglory was faster and maximum germination was recorded within 24 to 48 h. In earlier studies, maximum germination of these species was recorded at 20^{O}C after 24 h (Crowley and Buchanan, 1980). Similarly, tall morningglory has been found to germinate within 24 h in a temperature range of 15 to 35^{O}C with maximum germination at 25^{O}C (Cole and Coats, 1973; Frazee and Stoller, 1974). Germination of tall morningglory at a wide temperature range indicates its lower vulnerability to temperature fluctuations under field conditions. However, germination at 40 or 45^{O}C does not mean that it can thrive at that high temperature as all the germinated plants of annual morningglory died at 45^{O}C after germination. Some of the weed species may germinate at higher temperature, but may not grow at that high temperature. The optimum temperature for the germination of smallflower morningglory was 35 to 40^{O}C, but optimum growth was between 25 to 35^{O}C (Shaw *et al.*, 1987).

Germination of Florida beggarweed over a wide temperature range (20 to 45^{O}C) indicates its adaptation to Florida conditions where temperatures in spring and summer are high. Germination was significantly lower at 20/15 and 45/35^{O}C temperature, but still 66 and 59% seeds were able to germinate. It took longer time for seeds to germinate at 20/10^{O}C than higher temperatures (data not shown). Cardina and Hook (1989) found 21 to 38^{O}C as an ideal temperature for the germination of Florida beggarweed. No germination of Florida beggarweed was recorded at 10^{O}C and only 2% seed germinated at 45^{O}C (Reddy and Singh, 1992). Lower germination of Florida beggarweed at higher temperature by Reddy and Singh could be due to high alternating temperature of 45/40^{O}C as in the present experiment 59% germination was recorded at 45/35^{O}C photoperiod.

No germination of Florida pusley was reported at a constant temperature of 15^{O}C or lower and at 40^{O}C (Biswas *et al.*, 1975). In the present study, germination of Brazil pusley was recorded upto 45/35^{O}C alternating temperature; though it was 79% lower than at 30/25^{O}C. In the germination study of Florida pusley (Biswas *et al*., 1975), a constant temperature of 30^{O}C or alternating temperature of 20/30^{O}C provided complete germination, supports higher germination of Brazil pusley in the present study at alternating temperature of 30/20^{O}C.

Seed germination rate of Johnson grass has been found to increase with temperature upto 36^{O}C and then declined at 40^{O}C (Holshouser *et al.*, 1996). The trend was same in the present study where Johnson grass germination increased from 8 to 84% with increase in temperature from 20 to 35^{O}C and then decreased to 78 and 61% with increased temperature to 40 and 45^{O}C, respectively (Fig. 1). Germination of Johnson grass was 20-30% higher when incubated at 28 and 35^{O}C than at 10 or 22^{O}C (Huang and Hsiao, 1987). Incubating seeds at 35^{O}C had stimulatory effect on germination of Johnson grass, whereas it was inhibitory when incubated at 22^{O}C and no effect at 28^{O}C. Highest germination of Johnson grass at 35^{O}C and no germination at 15^{O}C suggest that seeds were in dormant stage at lower temperature regimes. Strong correlation of soil temperature and germination of Johnson grass have been reported earlier (Benech-Arnold *et al.*, 1988, 1990).

Higher fresh weight and radicle/hypocotyl length of strangler vine were recorded at a constant temperature of 30^{O}C or alternating 30/20^{O}C than at 20 or 15^{O}C (Singh and Achhireddy, 1984). Root/shoot length or fresh weight was not recorded in the present study, but the germination was greatly reduced with increase or decrease in temperature from 30^{O}C. Higher temperature was inhibitory to strangler vine seed germination than lower one as only 1% seed could germinate at 45^{O}C compared to 19% at 15^{O}C.

Redroot pigweed seeds kept under greenhouse and soil conditions were less affected by temperature for inducting secondary dormancy (Baskin and Baskin, 1977; Forcella *et al.*, 1997). Soil buried seed of pigweed when exhumed for germination test, exhibited more germination at higher than lower temperature (Gallaghar and Cardina, 1998). Schonbeck and Egley (1980) found that seed of pigweed stored for two years after ripening at -20^{O}C had highest germination at 39.5^{O}C and decreased significantly with decreasing temperature. In the growth cabinet study, pigweed was least affected by high temperature when compared to the entire test weed species (Fig. 2). Higher germination of pigweed was found in the range of 35 to 45^{O}C. Lower temperature was found to significantly reduce the germination of pigweed. Koch (1970) concluded that optimum temperature for germination of redroot pigweed seeds was 35 to 40^{O}C.

Contrary to pigweed, ragweed germination was greatly inhibited by higher temperature. A temperature of 25^{O}C in the greenhouse was reported to induct secondary dormancy in common ragweed seeds (Baskin and Baskin, 1977). Growth and development of ragweed have been found better in the temperature range of 8-31.7^{O}C (Deen *et al*., 1998).

Germination and growth of sicklepod were lower at 15^{O}C and peaked upto 36^{O}C (Teem *et al*., 1980). The germination was similar between 24 to 36^{O}C and reduced with increase or decrease in temperature; the length of radicle and hypocotyle was more affected than germination (Teem *et al*., 1980). Sicklepod was found to germinate at a range of 10 to 40^{O}C under Texas conditions, with 25 to 35^{O}C being ideal temperature range (Eastin, 1981). Higher weed dry weight, leaf area, plant height, node number and leaf number of sicklepod were recorded with temperature regimes of 29/26 and 34/26^{O}C under field conditions (Patterson, 1993). Growth parameters were adversely affected by lower temperature. Under higher temperature sicklepod was found to compete more vigorously with soybean than to low temperatures (Wright *et al*., 1999). This shows that the weeds adapted to higher temperature condition in south-eastern US respond more positively to competitive interactions with crops than at lower temperatures. These temperature characteristics help to explain why the intensity of weed pressure increases even as the crop growing season progresses, even after canopy closure.

Alternating higher temperature and wet/dry cycle have been found to promote prickly sida germination by breaking its dormancy (Baskin and Baskin, 1984). Germination of prickly sida was above 75% at alternate temperature regime of 25 to 45^{O}C in the present study which shows that it is well adapted to the high temperature conditions of southern USA. Germination was significantly reduced by decreasing temperatures of 25/15^{O}C and only 4% seeds germinated at 15/10^{O}C (Fig. 2). In another study, maximum germination of teaweed was reported at 35 or 40^{O}C; seed of teaweed could withstand 45^{O}C temperature upto 21 days with 50% loss of viability (Smith *et al*., 1992).

Under constant temperatures of 15, 20, 25, 30 and 35^{O}C with or without light (78 µmol/s/m^2 for 8 h), highest germination (85%) of *Peschiera fuchsiaefolia* (DC) Miers. was observed under 25 and 30^{O}C, but light exposure had no significant effect on seed germination (Martins *et al*., 2000). The lower temperature limit required for the germination of tropical and temperate weeds was estimated 10-20^{O}C and 5^{O}C, respectively; maximum being 40 ^{O}C and optimum germination at 15-40 ^{O}C and 15-25°C for the tropical and temperate species, respectively (Sauerborn *et al*., 1988). *Eleusine indica* (goosegrass) germination was greater at higher alternating temperature (30/20 and 35/25^{O}C) than at lowest alternating temperature (25/15^{O}C) (Chauhan and Johnson, 2008a).

Yellow nutsedge is adapted to wider temperature range and optimum growth occurs at high temperature. Experiment conducted under constant temperature on bud sprouting of yellow nutsedge in dark revealed that percentage sprouting increased in the range of 12 to 38^{O}C (Li *et al*., 2000). No sprouting occurred at 10^{O}C and only few at 42^{O}C. The rate of sprouting increased upto 35^{O}C which is in conformity with present study data showing maximum germination at 30 or 35^{O}C. Higher temperature resulted in greater root : shoot mass and is thus critical for the establishment of yellow nutsedge. Higher temperature of 50 or 55^{O}C can cause 100% mortality of yellow nutsedge (Chase *et al*., 1999). The 45^{O}C temperature was not lethal to tubers, though delayed germination was recorded. Germination of another perennial sedge, *Kyllinga brevifolia* (green kyllinga) occurred between 17 to 30^{O}C, but germination was maximum between 20 and 24^{O}C (Mollin *et al*., 1997).

Effect of Light Exposure on Germination

Dark adaptation of seeds had no effect on weed species germination as statistically similar germination was recorded from different light exposure durations. Germination of tall morningglory, Florida beggarweed, ivyleaf morningglory, Johnson grass and strangler vine was not affected by light or dark conditions, whereas lower germination was recorded for Brazil pusley when seeds were kept in dark upto 16 h (Fig. 3). Seed of

Brazil pusley placed in light from 0 to 16 h intervals and subsequently under dark conditions, till 168 h had only 2-10% germination compared to 59% when seeds were not subjected to dark conditions (Fig. 3).

Similarly, redroot pigweed, sicklepod, hairy beggarticks, prickly sida and yellow nutsedge germination was not affected by light exposure (Fig. 4). Sauerborn *et al*. (1988) studied the effect of light exposure and dark adaptation on some tropical (*Ageratum conyzoides*, *Bidens pilosa*, *Digitaria horizontalis*, *Eleusine indica*, *Euphorbia hirta* and *Ludwigia hyssopifolia*) and temperate weed species (*Alopecurus myosuroides* and *Chenopodium album*) and found good germination of all species under light, but *A. conyzoides* and *L. hyssopifolia* failed to germinate in the dark.

On the other hand, germination of common ragweed was almost 50% lower under dark adaptation than under light (Fig. 4). Reduction in germination was less in common ragweed compared to Brazil pusley when seeds were placed in dark after 0 to 16 h exposure to light, but there were no differences among different durations.

Light has been found to stimulate the germination of goosegrass (*Eleusine indica*) (Fulwider and Engel, 1959), mulberry (*Fatoua villosa*) (Penny and Neal, 2003), prostrate spurge (*Euphorbia supina*) (Krueger and Shaner, 1982), Florida pusley (*Richardia scabra*) (Biswas *et al*., 1975), and dog fennel (*Eupatorium capillifolium*) (MacDonald *et al*., 1992), Parthenium (Dhawan and Dhawan, 1994), but it was not found essential for germination of goosegrass (Toole and Toole, 1940) and kutzu (*Pueraria lobata*) (Susko *et al*., 1999).

Similarly, germination of prickly sida was not influenced by light (Smith *et al*., 1992).

Germination of common ragweed was significantly higher under light conditions compared to light exposure from 0 to 16 h (Fig. 4); however, almost 50% seeds germinated under dark conditions and there was no difference in light exposure durations of 0.5 to 16 h. Similar observations were recorded by Baskin and Baskin (1980) for light requirements of common ragweed for germination.

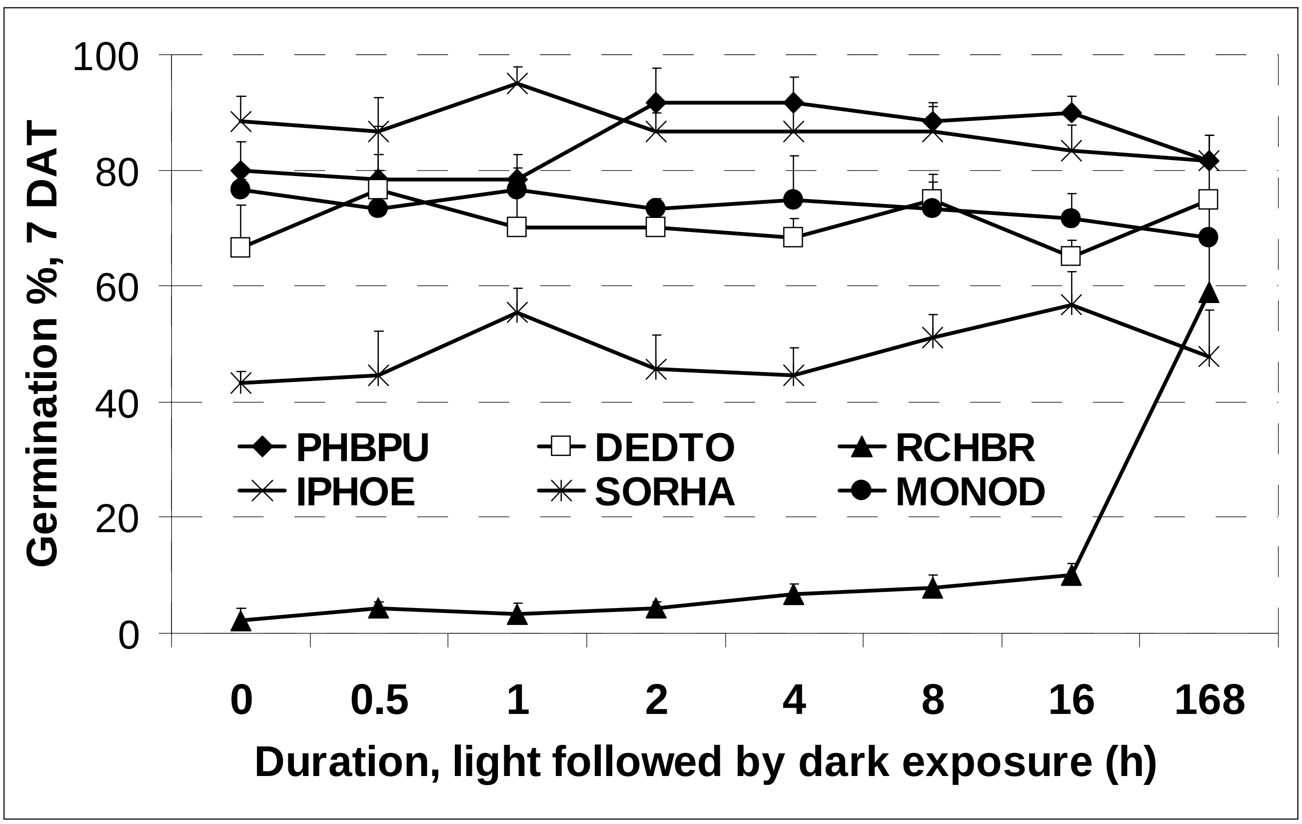

Fig. 3. Effect of light on the germination of tall morningglory (PHBPU), Florida beggarweed (DEDTO), Brazil pusley (RCHBR), ivyleaf morningglory (IPOHE), Johnson grass (SORHA) and strangler vine (MONOD). Bars indicate standard error of means.

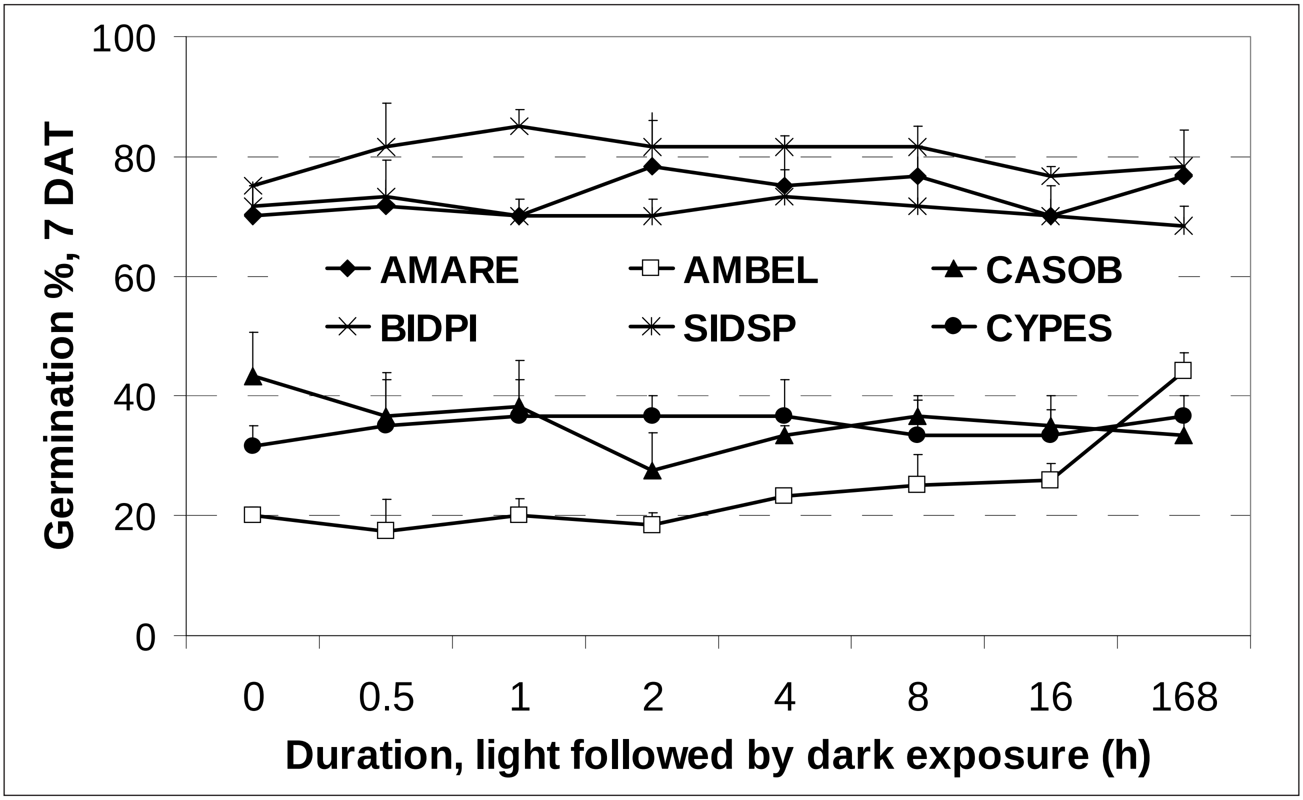

Fig. 4. Effect of light on germination of pigweed redroot (AMARE), common ragweed (AMBEL), sicklepod (CASOB), hairy beggarticks (BIDPI), prickly sida (SIDSP) and yellow nutsedge (CYPES). Bars indicate standard error of means.

Effect of pH on Germination

There were no differences in germination at pH values from 5 to 11, when data were averaged over species. Germination was negligible at pH 3 for most weed species. Tall morningglory, Florida beggarweed, Brazil pusley, ivyleaf morningglory, Johnson grass and strangler vine had no germination at pH 3, but similar germination was observed at pH 5, 7, 9 and 11 (Fig. 5). Variations in germination were observed among the weed species, but pH from 5 to 11 had similar germination of the test species.

Germination of redroot pigweed, hairy beggarticks and sicklepod was similar at pH of 5, 7, 9 and 11; none of them germinated at pH 3 (Fig. 6). Common ragweed, though had lowest germination among the tested weed species, germination was higher at pH 5 and decreased with increase in pH; there was no germination at pH 3 (Fig. 6). In case of prickly sida, highest germination was recorded at pH 9 and germination decreased both with increase or decrease in pH from 9 (Fig. 6). No germination of prickly sida was recorded at pH 3; germination was similar at pH 7 and 11, but higher than pH 5. Only yellow nutsedge could germinate at pH 3, but germination was significantly lower than other pH values (Fig. 6). Highest germination of yellow nutsedge was recorded at pH 7, compared to lower or higher pH, but statistically no difference was observed between pH 5 to 11.

Similar germination of Florida pusley was recorded at a pH range of 3 to 8 (Biswas *et al.*, 1975). In a greenhouse study, germination of common ragweed and other weed species was found better between 5.3 to 5.5 pH range and increasing soil pH above 5.5 either stabilized or reduced the number of weed seeds germination (Stephenson and Recheigl, 1991). Though overall germination of common ragweed in the present study was low due to seed dormancy, but effect of pH was visible on germination. Highest germination of common ragweed was at pH 5 and it decreased with increase in pH value. A pH of 3 was inhibitory to the germination of most weed species except yellow nutsedge under growth cabinets (Fig. 6). Germination

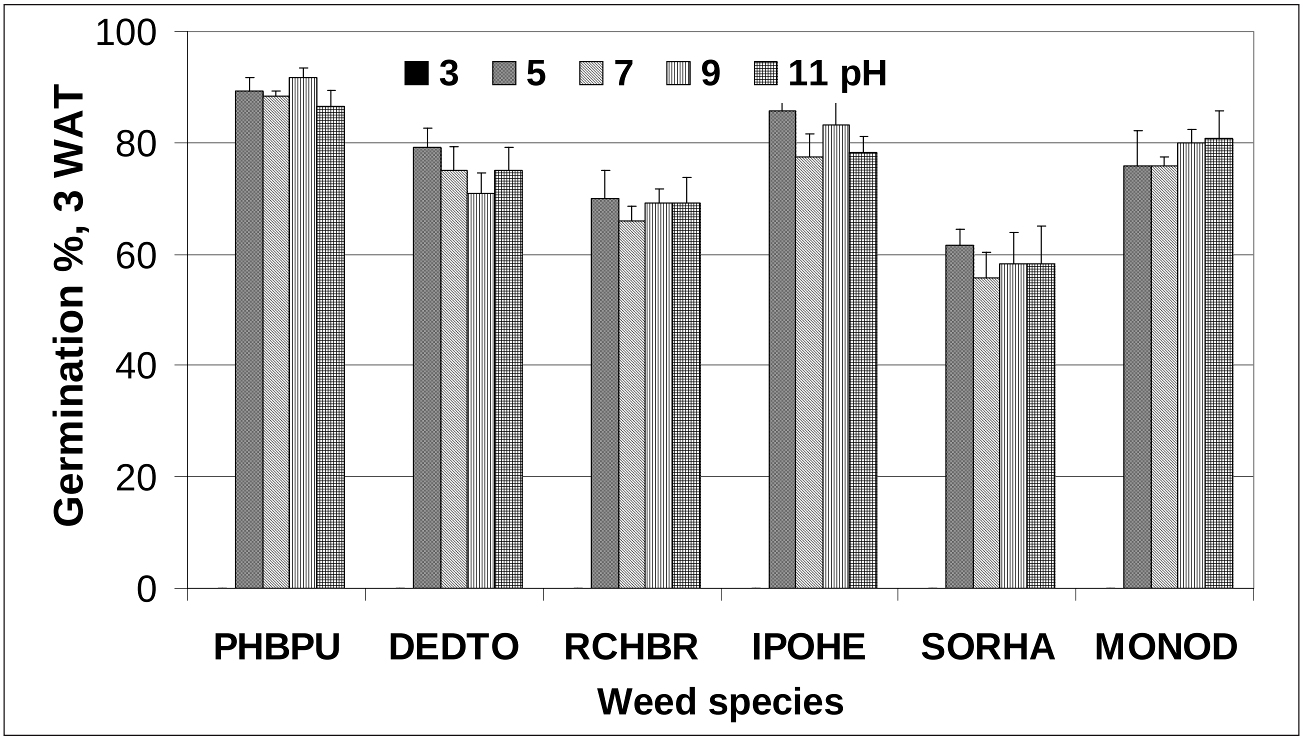

Fig. 5. Effect of pH on the germination of tall morningglory (PHBPU), Florida beggarweed (DEDTO), Brazil pusley (RCHBR), ivyleaf morningglory (IPOHE), Johnson grass (SORHA) and strangler vine (MONOD). Bars indicate standard error of means.

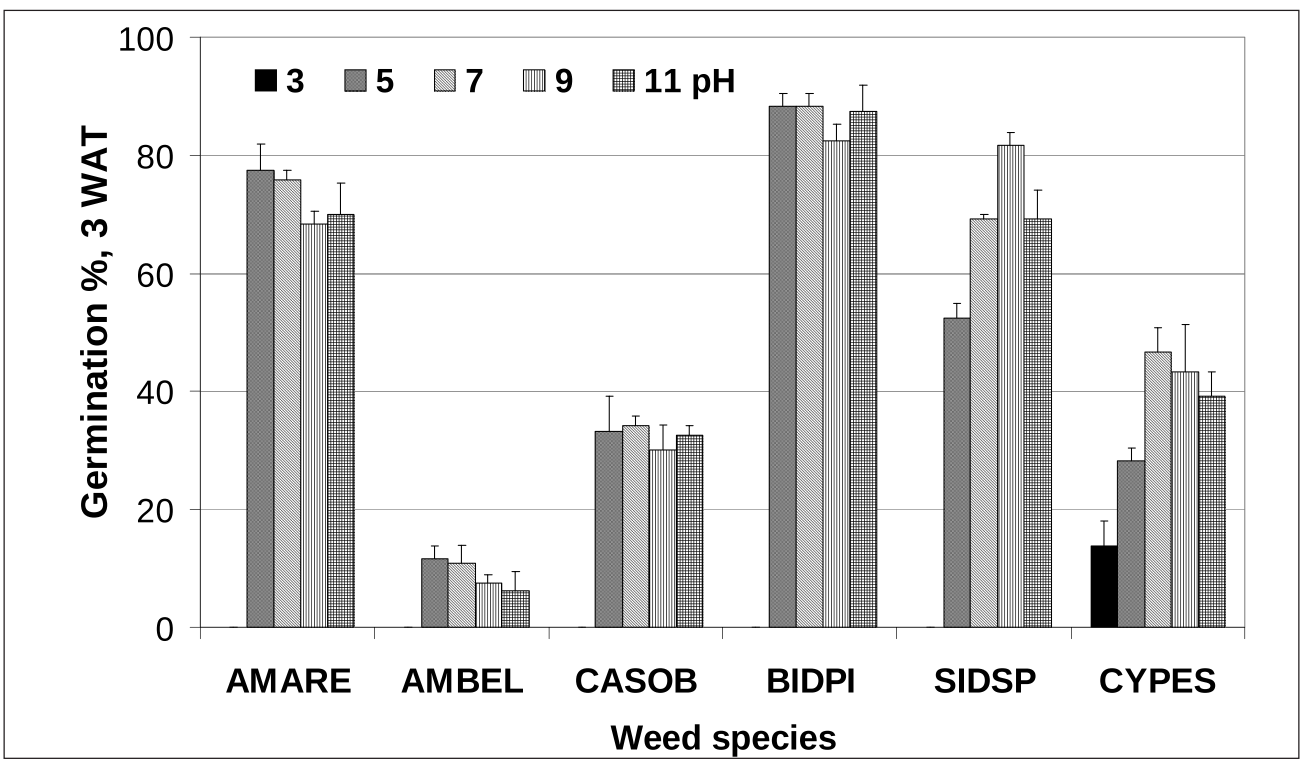

Fig. 6. Effect of pH on germination of pigweed redroot (AMARE), common ragweed (AMBEL), sicklepod (CASOB), hairy beggarticks (BIDPI), prickly sida (SIDSP) and yellow nutsedge (CYPES). Bars indicate standard error of means.

of yellow nutsedge was greater at pH 7 to 11. Similarly, hairy beggarticks (*Bidens pilosa*)–a ubiquitous weed of orchards, field bunds and non-cropped areas across the continents was found to have a high degree of tolerance to extreme pHs, though had a tendency of greater development close to neutral pH (Obara *et al.*, 1994). Germination of *Kyllinga brevifolia* was uniform between pH 5.5 to 9.5 (Mollin *et al.*, 1997) and between 5 to 9 pH for *P. lobata*, though maximum germination occurred at 5.4 pH (Susko *et al.*, 1999).

Buchanan *et al*. (1975) found significant variations in the growth of several warm and cool season weeds when grown in glasshouse with field soil of different pH levels. *Crotalaria spectabilis*, *Cassia occidentalis* and *Digitaria sanguinalis* were highly tolerant to low pH soils. *Cassia obtusifolia*, *Poa annua*, *Geranium carolinianum* and *Plantago lanceolata* were medium to high in tolerance. *Datura stramonium*, *Ipomoea purpurea*, *Dactyloctenium aegyptium* and *Sida spinosa* were medium to low in tolerance to low soil pH, whereas growth of *Desmodium tortuosum*, *Amaranthus retroflexus*, *Stellaria media*, *Taraxacum officinale* and *Brassica kaber* var. pinnatifida [= *Sinapis arvensis*] was severely reduced in soils with low pH.

Significant interaction of temperature and light was observed for germination of *Amaranthus retroflexus*, where requirement of light (red) was more pronounced at 20 than 30^{O}C (Gallagher and Cardina, 1998). Floristic composition under fields is greatly influenced by soil pH. The competitive ability of redroot pigweed was greater at a higher pH of 7.5 than at 5.5 (Anonymous, 1980). The present study was short to deal with competitive ability of weed species at different pH levels; but several reports on weed survey underline the importance of soil pH on field weed infestation.

Germination of *Eclipta prostrata* (false daisy) completely inhibited in the dark, whereas in the light/ dark it was 76, 93, and 87% at 25/15, 30/20 and 35/ 25^{O}C alternating day/night temperatures, respectively (Chauhan and Johnson, 2008b). On the other hand, jungle rice (*Echinochloa colona*) germination was stimulated by light, but not influenced by (35/25, 30/20 and 25/15^{O}C) alternating day/night temperatures (Chauhan and Johnson, 2009).

The temperature range of 28 to 32^{O}C, found optimum for germination of a large number of weed species, has been shown to coincide with a phase transition of membrane (Hendricks and Taylorson, 1979). Increased germination at higher temperature has been assigned to increased sensitivity of seeds to a low level of pre-existing active form of phytochrome. Differential germination of weed seeds at constant or alternating temperatures is influenced by permeation of amino acids (Hendricks and Taylorson, 1976). The physiological response of seed varies with change in temperature and light conditions.

Gallaghar and Cardina (1998) reported light requirement for the germination of redroot pigweed; however, higher temperature can compensate the role of light and it may be crucial only for freshly harvested seed with inherent dormancy. In the present study, seeds of only Brazil pusley and common ragweed have shown reduced germination under dark. Presumably, dormancy might have played some role as these seeds were freshly procured; all other weed seeds were at least five years old, but no dormancy tests were carried out.

The phytochrome and high temperature act as a trigger to initiate a chain of events leading to germination (Takaki *et al*., 1981). Elevated temperature has been shown not only to enhance the sensitivity of seeds phytochrome, but also induces the appearance of phytochrome in the dark. A short light exposure of 5 min at 35^{O}C has been found to compensate the light requirement for germination (Takaki *et al*., 1981). A temperature of 30^{O}C in the present study might have overcome the light requirements as 10 out of 12 weed species and showed no effect of dark conditions on germination. Higher germination of freshly harvested dormant seed of prickly sida was recorded at 35 than 15 or 25^{O}C under dark conditions (Egley, 1976). Germination of 9 month stored seeds at 25^{O}C was similar under dark or light conditions at 35^{O}C.

Regulating soil microclimate (temperature, pH and light exposure) through field preparations, irrigation, soil amendments and cultural practices can be employed to lower weed infestation by inhibiting weed germination. This approach; however, may not work for all weed species, but can be successfully integrated for individual dominant weed species exploiting the differential germination influenced by temperature, light conditions and soil pH.

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