We no longer need to add acid to the system to reduce our abnormally high pH which we find can reach 9.5 in winter.

There has been no build up of chemicals. The phosphate is being managed by reducing this portion of the fertiliser. As all nutrition being applied is being controlled by the use of conductivity the same procedure reduces the phosphate applications. We have estimated that we are saving in excess of 20% of our phosphate purchases.

No water is being returned to the river and all water is being re-used.

Pumping costs to move water 600 m at a head of 80 m has been reduced. We still need to evaluate this but we know that this saving is significant.

At certain times we run for days on end from the recycling plant only. What is extremely rewarding is to see that in general the seedlings look healthier.

If anyone would like to correspond with the author on this subject please feel free to do so on topcrop@intekom.co.za or topcrop@lantic.co.za

---

A Germination Strategy for Seed of Verbena ×*hybrida*

A.C. Lubbe
Department of Horticulture, Technikon Pretoria, Private Bag X680, Pretoria, 0001, South Africa

The influence of temperature on *Verbena*×*hybrida* Voss seed germination was evaluated in terms of current germination recommendations to overcome erratic and low germination.

During three experiments, nondormant seeds were exposed to continuous constant temperatures and alternating diurnal temperatures. Seeds were germinated on germination paper inside clear petri dishes, using dark temperature-controlled incubators.

Cumulative germination was modelled by the Weibull distribution function, correlating closely ($R2 \geq 0.99$) to the observed germination data. No germination occurred at constant 10°C. Significantly ($P \geq 0.05$) reduced germination occurred at constant 15°C and at irregular fluctuating temperatures, while 25°C was assumed as a cardinal constant temperature. Controlled fluctuations did not significantly reduce germination.

It is recommended that only hermetically sealed verbena seeds are germinated according to current germination recommendations, at any temperature regime between 28°C day and 14°C night temperatures, ensuring constant amplitudes during temperature fluctuations.

INTRODUCTION

The cultivation and utilization of bedding plants are dependent on seed germination, and the potential to germinate is economically important (Armitage, 1994; Bewley and Black, 1985 and Hartmann et al., 1997).

Verbena ×hybrida is a tender perennial grown commercially by all major bedding plant producers in Gauteng, indicating its economical value. Germination is erratic with total germination between 40% and 60% (Carpenter and Maekawa, 1991; Duif,

personal communication, 1996; Nau, 1993). Growers consequently do not enjoy a viable return on investment.

Production seasons in Gauteng province in South Africa are characterised by relatively high and fluctuating temperatures. To maintain a greenhouse near the recommended 20°C is difficult and costly, if not near impossible, during these seasons. According to Armitage (1994) temperature is the most important environmental factor governing seed germination rate and germination percentage.

Previous results indicated that verbena seeds should be germinated under dark and dry conditions, while temperature recommendations per sé varied between 15 to 30°C (Armitage, 1994; Atwater, 1980; Ball, 1991; Hartmann et al., 1990; Heit, 1965; Maekawa and Carpenter, 1991; Nau, 1993 and Styer and Laffe, 1989). The most recently consulted literature recommends verbena seeds to be germinated at 24°C (days) and 15°C (nights) (Hartmann et al., 1997). Despite the practical application of the abovementioned germination recommendations, unfavourable crop yields persistently render uneconomical crop values.

This research therefore proposed to evaluate verbena seed quality in terms of seed viability. Seed germination value was tested in terms of the influence of temperature on germination percentage and germination rate in order to overcome erratic germination patterns and low germination percentages.

MATERIALS AND METHODS

Three separate experiments were conducted during March to June 1997. Each experiment lasted for 14 days. In each experiment, seeds were germinated in clear plastic petri dishes, placed inside dark temperature-controlled incubators. One control test was subjected to greenhouse conditions. All experiments were conducted in the facilities at Technikon, Pretoria, South Africa.

Hermetically sealed seeds of verbena were collected during March 1997. All seeds were from a standard commercial seed lot representing the cultivar 'Romance'. On receipt, all seeds (24 g) were stored at room temperature of ± 23°C. Each working sample consisted of 400 seeds, representing the individual treatments of each experiment. Each treatment consisted of four replications of 100 seeds. Visual inspection for pathogens was performed during incubation for the duration of each experiment.

To ensure optimum oxygen exchange, all substrates and petri dishes were treated similarly in terms of relatively low moisture levels and temperature regimes (Hartmann et al., 1997). In each case constant moisture levels were maintained by supplying 2-ml distilled water every 4 h for each replication, for the duration of each experiment. Germination counts of seeds with 1-mm radicle protrusion through the testa were made every 4 h for the duration of each experiment. All germinated seeds were discarded.

Temperature Treatments for Experiment 1. There were five treatments and one control. Seeds were exposed to constant temperatures: 10, 15, 20, 25, or 30°C. The control was subjected to normal fluctuating greenhouse conditions. Ambient greenhouse temperatures were measured every 4 h and daily minimum and maximum observations were noted.

Temperature Treatments for Experiment 2. Five treatments were subjected to alternating temperatures of 27/20°C, 29/20°C, 31/20°C, 33/20°C and 35/20°C, respectively, at 16/8-h cycles in each case. The control was subjected to constant 20°C.

Temperature Treatments for Experiment 3. There were five treatments and one control. The treatments were subjected to alternating temperatures of 28/10°C, 28/12°C, 28/14°C, 28/16°C and 28/18°C, respectively, at 16/8-h cycles in each case. The control was subjected to constant 28°C. All treatments were physically transferred from the relatively low temperature regimes to the control temperature regime and vice versa, according to the 16/8-h cycle.

Duncan's Multiple Range Test for variables was used to indicate significant differences. For each of the experiments, the cumulative Weibull distribution function was fitted to the cumulative germination data in order to analyse and model the germination responses of all the temperatures (Brown, 1987; Dumur et al., 1990). The Statistical Analysis System software program was used:

$$\mathbf{y = M\,[1\text{-}exp\{\text{-}k(t\text{-}l)^{c}\}]}$$

where y is the cumulative germination at time t, M is the maximum cumulative germination, k is the rate of germination (hours), l is the interval (lag) between the start of incubation and the start of germination and c is a shape parameter which describes the shape of the cumulative germination curve, especially in terms of its degree of skewness. Values lower than 3.6 indicate positively skewed distribution, while greater values indicate negative skewness. Values of ± 3.6 indicate symmetrical distribution (Dumur et al., 1990).

RESULTS

Precautions in terms of hygiene were successful, as no pathogenic infections were found. The seeds were relatively easy to handle and radicle protrusion through the testas were easily observed.

Experiment 1. During Experiment 1, at fluctuating greenhouse temperatures, as well as at relatively lower constant temperatures, significantly less seeds germinated over a longer period than at the relatively higher constant temperatures. The highest percentage germination was observed at constant 20 and 25°C, while no germination occurred at constant 10°C. A germination percentage as high as 91% was observed in one of the treatments (Fig. 1).

Duncan's Multiple Range Test for variables indicated a significant difference (P=0.0135) between the 10, 15, and 20°C treatments, as well as the greenhouse control treatment and the constant temperature treatments on a 5% level of significance. No significant differences were indicated between the 20, 25, and 30°C treatments.

In general, the Weibull distributions for the constant 20, 25 and 30°C temperatures correlated very closely with the actual data and two of the three coefficients of correlation exceeded 0.99.

Experiment 2. During the second experiment, seeds were subjected to constant 20°C night temperatures and different alternating day temperatures. Seeds germinated significantly more in less time at temperature regimes with relatively small fluctuations (7 to 11°C), than during relatively higher fluctuations (13 to 15°C). Germination percentages ranging from 63% to 89% were observed (Fig. 2).

An analysis of the Weibull constants (k) and (c) shows that the rate of germination decreased at the extreme temperature regimes, while more positively skewed

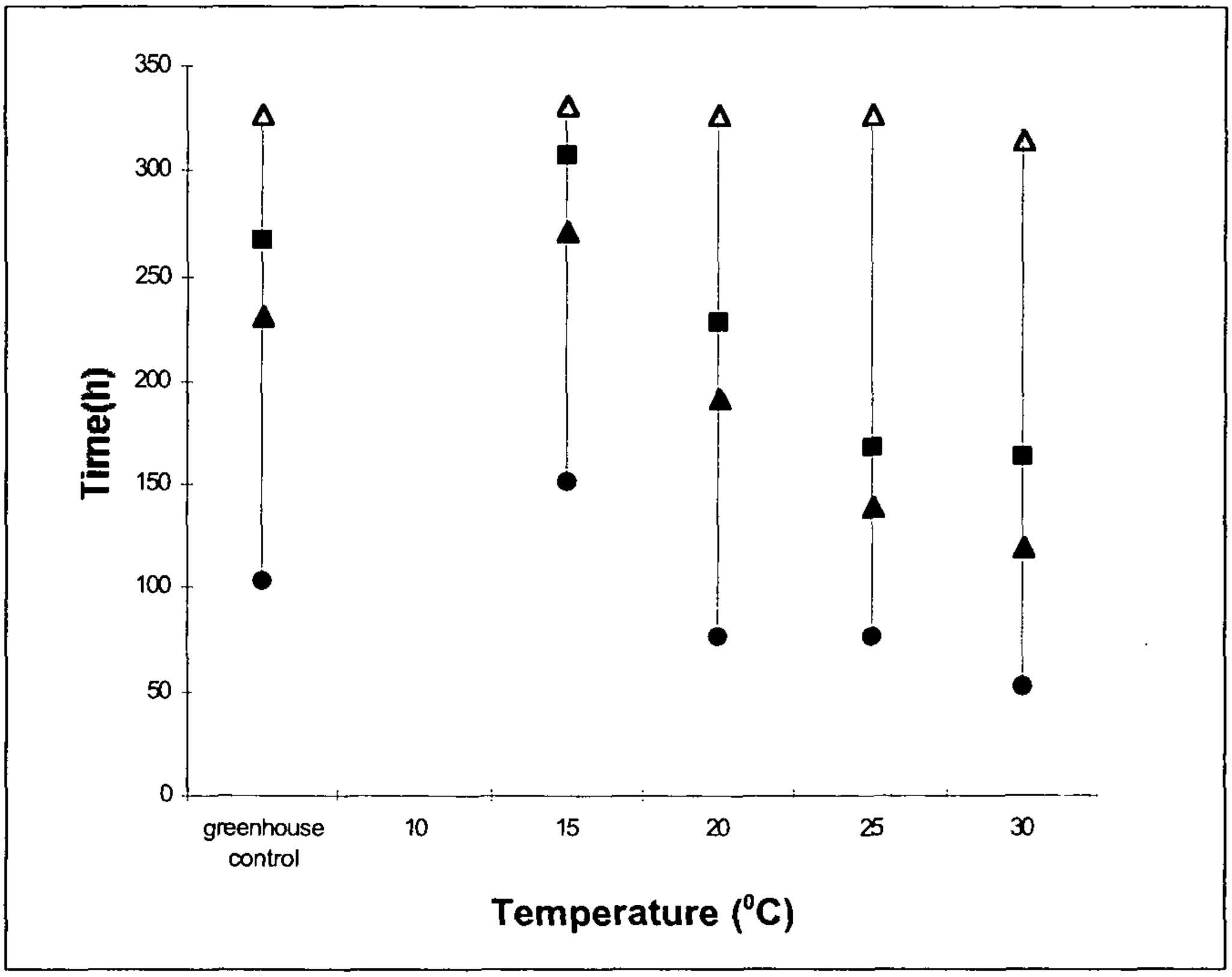

Figure 1. Time to onset (h) and spread of germination in *Verbena ×hybrida* seed, in response todifferent constant temperatures (°C). Symbols: (●)represents start of germination, (▲)represents 50% germination, (■)represents 80% germination, (△)represents total germination.

germination curves are estimated for the lower temperature regimes. This is similar to the actual germination observations. The delay in the start of germination (*l*) correlates well with the actual data for all the temperature regimes. The shape parameters (*c*) indicate positive skewness at all the temperature regimes, except at the extreme temperatures of 33/20 and 35/20°C. In general, the Weibull distributions for all the temperature regimes correlated very closely with the actual data and all the coefficients of determination (R^2) exceeded 0.99.

Experiment 3. In Experiment 3, seeds were germinated at constant 28°C day temperatures and at different alternating night temperature regimes ranging from 10 to 18°C. Duncan's Multiple Range Test for variables indicated no significant differences between any of the temperature regimes (P = 0.976) on a 5% level of significance. Germination percentages ranging from 82% to 91% were observed (Fig. 3).

The Weibull parameters demonstrates that generally the distributions correlated very closely with the actual observed data. All the coefficients of determination exceeded 0.99.

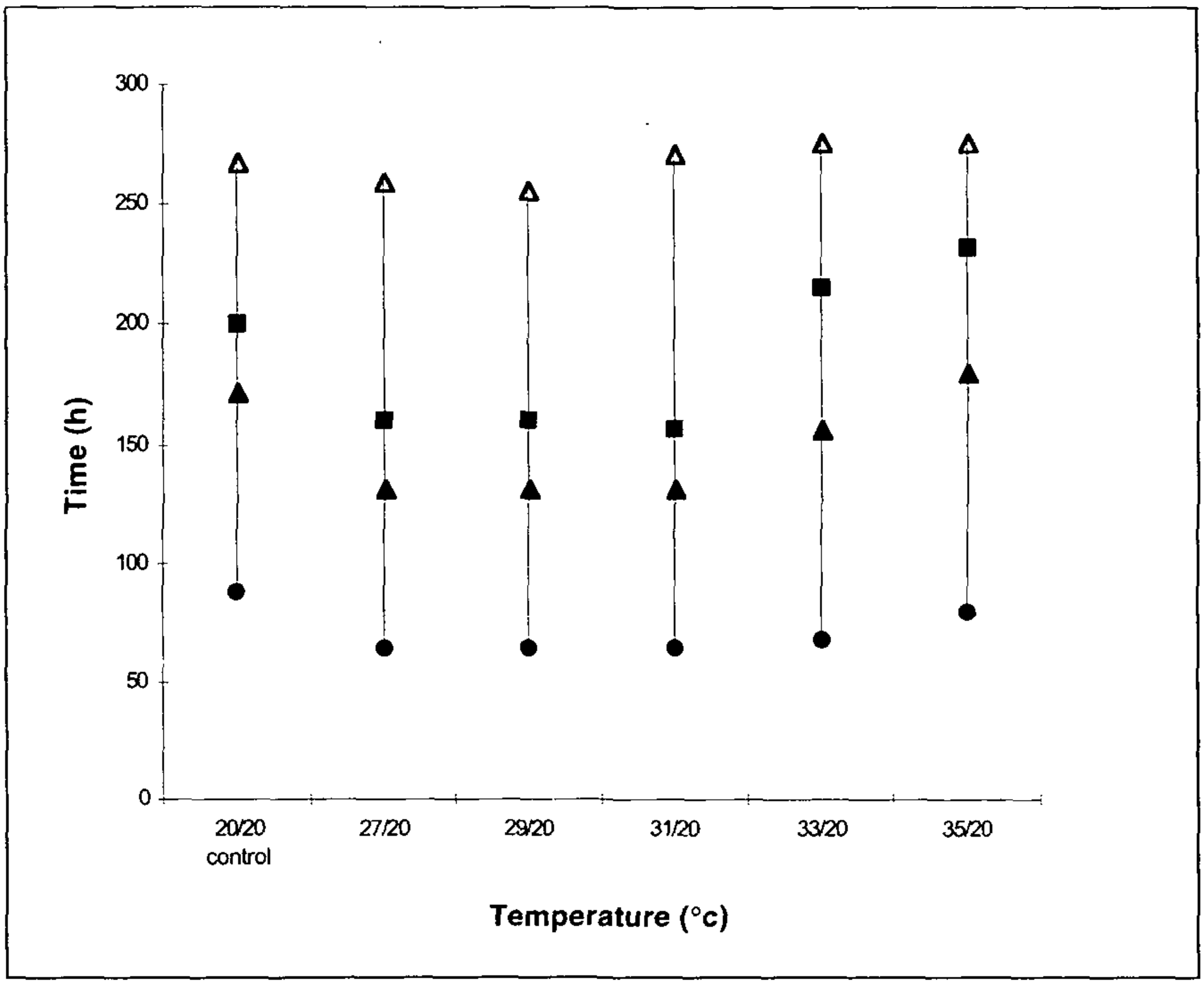

Figure 2. Time to onset (h) and spread of germination (h) in *Verbena ×hybrida* seed, in response to different alternating temperatures, with constant 20°C night temperature. Symbols: (●) represents start of germination, (▲)represents 50% germination, (■)represents 80% germination, (△)represents total germination. Duncan's Multiple Range Test for variables indicated a significant difference (P = 0.0068) between the 33/20°C, and the 35/20°C alternating regimes and the other three treatments including the control treatment on a 5% level of significance.

DISCUSSION

Germination problems during bedding plant production are a reality. A sound knowledge of the basic germination process per sé and also of the influences of environmental variables and diseases on seed germination, must be understood and managed accordingly. Germination recommendations for *V. ×hybrida* seed appeared to be inconsistent, particularly in terms of recommended temperatures. Germination responses in terms of moisture, gaseous exchange, light, and disease control corresponded with previous research.

Seed germination performance during controlled laboratory conditions suggests that verbena seeds are capable of rapid germination at ≥ 80% with no pathogenic infection, probably due to the absence of freewater on the germination substrate. Thus, verbena seed quality appears not to be only inherently dependent on the seed, but rather on the germination practices. These observations provide practical support to previous hygiene guidelines (Nau, 1993).

It was assumed that *V. ×hybrida* would react as a high-temperature-requiring crop, in terms of current germination recommendations. This assumption was

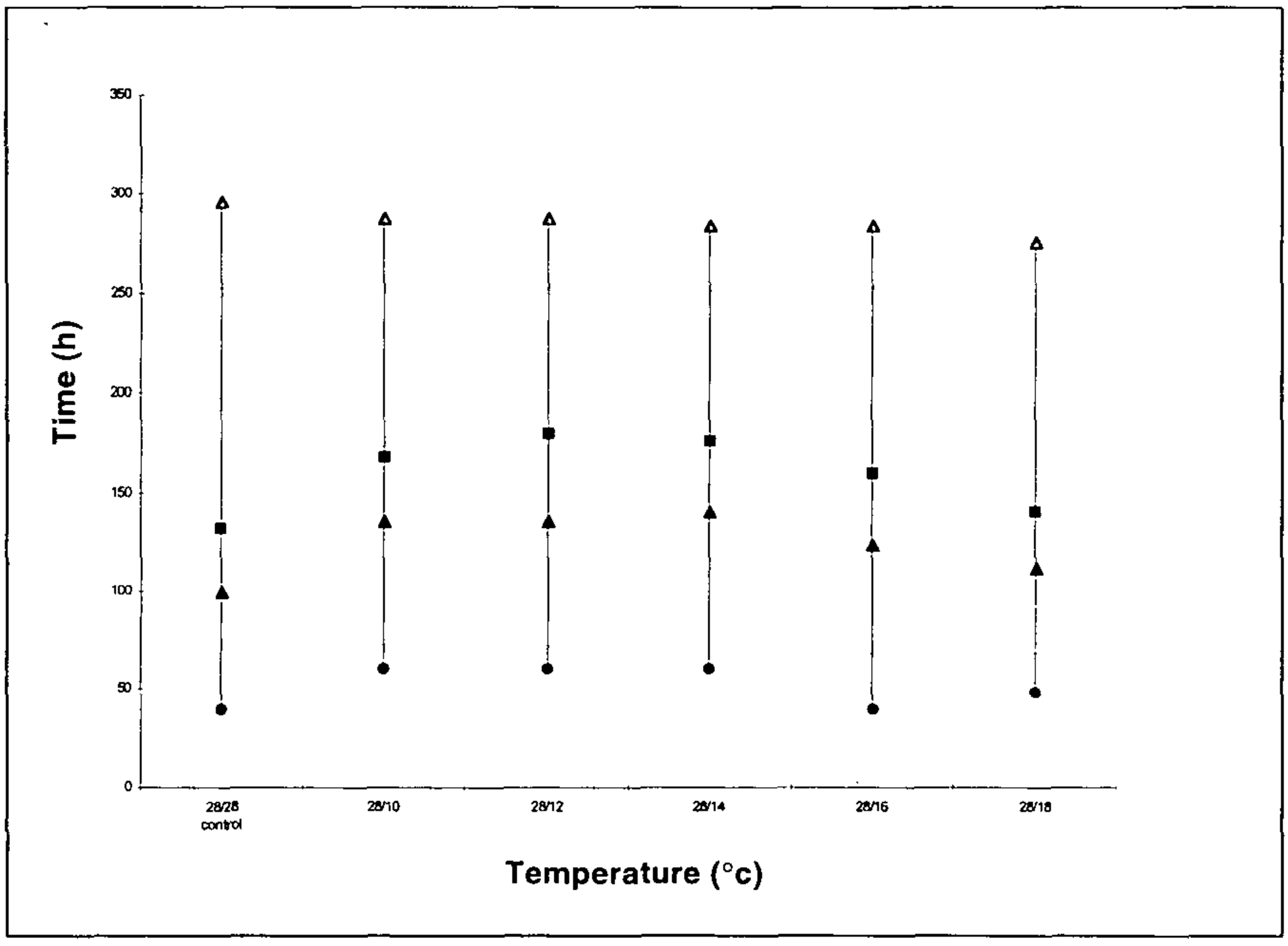

Figure 3. Time to onset (h) and spread of germination (h) in *Verbena ×hybrida* seed, in response to different alternating temperatures, with constant 28°C day temperature. Symbols: (●) represents start of germination, (▲)represents 50% germination, (■)represents 80% germination, (△)represents total germination.

based on the fact that *V. ×hybrida* originated in tropical southern Brazil (Jones and Luchsinger, 1987). This is of practical significance, because relatively constant high temperatures associated with humid, dark forest conditions characterize such tropical areas. The assumption appeared to be true for *V. ×hybrida*. Contrary to conditions in its original habitat, greenhouse temperature fluctuations were erratic with varying amplitudes. These uneven temperature fluctuations might have inhibited initial embryo development, possibly due to abnormal respiration and enzyme activities (Atwater, 1980). Thus, set greenhouse temperatures must be carefully monitored to prevent uneven temperature fluctuations, particularly at the start of germination.

Observations were made every 4 h rather than daily. This provided more data and consequently greater accuracy, particularly because of using the Weibull distribution function. This is of practical significance because not only total germination percentage would be measured, but practical information of the start, spread, and the cumulative extent of seed germination at each temperature treatment, would be provided. This is possible because of the multi-parametered nature of the Weibull function and its ability to model cumulative germination. Constant 25°C indicated significant practical value in terms of both germination percentage and germination rate and is recommended as an optimum constant temperature for verbena seed germination. Alternating temperatures often present better gemination results

than at constant temperatures (Hartmann etal., 1997). This possibly happens because the temperature fluctuation effect decreases with sowing depth (Thompson and Grime, 1983). In the case of verbena this is of practical significance because of the small seed size and its sensitivity to moisture, as well as its requirement for darkness.

CONCLUSION

It is recommended that nondormant *V.* ×*hybrida* seeds are germinated in darkness, with no free-water on the substrate and at any manageable constant temperature regime between 28°C day and 14°C night temperatures. Temperature fluctuations must remain even for the duration of germination.

Acknowledgement. The author would like to express his appreciation to Straathof's Group for financial assistance.

LITERATURE CITED

Armitage, A.M. 1994. Ornamental bedding plants. CAB International, Wallingford.

Atwater, B.R. 1980. Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technol. 8:523-573.

Ball, V. (ed.). 1991. Ball red book: Greenhouse growing. 15th Ed. Geo. J. Ball Publishing. West Chicago, Illinois.

Bewley, J.D. and **Black, M.** 1985. Seeds: Physiology of development and germination. Plenum Press, New York.

Brown, R.F. 1987. Germination of *Aristida armata* under constant and alternating tempera- tures and its analysis with the cumulative Weibull distribution as a model. Aust. J. Bot. 35:581-591.

Carpenter, W.J. and **S. Maekawa.** 1991. Substrate moisture level governs the germination of verbena seed. HortScience 26(12):1469-1472.

Duif, J. 1996. Straathof's Seeds, PO Box 3691, Honeydew, 2040, South Africa.

Dumur, D., C.J. Pilbeam, and **J. Craigon.** 1990. Use of the Weibull function to calculate cardinal temperatures in faba bean. J. Exper. Bot. 41(232):1423-1430.

Hartmann, H.T., D.E. Kester, and **F.T. Davies.** 1990. Plant propagation: Principles and practices. 5th ed. Prentice Hall, New Jersey.

Hartmann, H.T., D.E. Kester, F.T. Davies, and **R.L. Geneve.** 1997. Plant propagation: Principles and practices. 6th ed. Prentice Hall, New Jersey.

Heit, C.E. 1963. Verbena seed sensitiveness to moisture during laboratory germination testing. Proc. Assoc. Official Seed Analysts, 53:96-99.

Jones, S.B. and **A.E. Luchsinger.** 1987. Plant systematics. 2nd ed. Mcgraw-Hill, Singapore.

Maekawa, S. and **W.J. Carpenter.** 1991. Verbena seed hilum morphology contributes to irregular germination. HortScience 26(2):129-132.

Nau, J. 1993. Ball culture guide: The encyclopedia of seed germination. 2nd ed. Ball Publishing, Batavia, Illinois.

Steyer, R.C. and **S. Laffe.** 1989. How to get your germination rates on the rise. Grower Talks 53(8):55-60.

Thompson, K. and **J.P. Grime.** 1983. A comparative study of germination responses to diurnally-fluctuating temperatures. J. Applied Ecol. 20:141-156.