Germination and emergence of amaranth cultivars: Water potential, temperature, seed size and sowing depth

ESTER C CASENAVE*, MARÍA E TOSELLI and SILVIA T CANTOS

Facultad de Agronomía y Agroindustrias, Universidad Nacional de Santiago del Estero, Santiago del Estero, Argentina

Poor seedling emergence is a major limitation in establishing amaranth when there is insufficient moisture and high temperatures in the upper layer of the soil at sowing time. One method used to improve emergence and seedling vigor for deep sowing is the utilization of heavier or larger seeds because they have been found to increase percent emergence or germination. This study was conducted in order to identify (i) whether germination differences were detectable at different water potentials and temperatures, and (ii) whether emergence differences were detectable among different cultivars, seed size, and sowing depth. At all temperatures, with the exception of Don Manuel, seeds of all cultivars ceased to germinate when exposed to -0.8 MPa water potential. Optimum temperature was around 30°C in water stress. Don Juan was the most sensitive cultivar with a large reduction at 40°C, even in 0 MPa water conditions. Don Armando, Don Guiem and Don Manuel were practically temperature insensitive in water potentials from 0 to -0.4 MPa. Emergence percentage averaged across all cultivars and seed size significantly decreased as sowing depth increased from 53% at 2 cm to 29% at 4 cm and 12% at 6 cm. Medium and large size seeds had significantly more emergence percentage than small ones. Deep sowing significantly delayed emergence. These differences in average time to emergence (A_{te}) may be large enough to be of practical importance. In conclusion, data from this experiment show that even with favorable soil moisture, sowing amaranth deeper than 2 cm delayed and decreased emergence. The effect of high soil surface temperature on seedling emergence may not be a limiting factor under unlimited soil water conditions, but cultural practices that extend the period of high soil water potentials should be applied to improve the establishment of amaranth. Deeper sowing may be practical if seeding rates are adjusted to compensate for reduced percentage emergence associated with depth.

Key terms: *amaranth, emergency, germination, stress.*

INTRODUCTION

Amaranths (*Amaranthus spp.* L) are rather bushy plants which show promise as a quick-maturing crop for the dry-season in monsoon areas. They have been receiving much attention recently because of their high nutritive value and favorable agricultural advantages, like drought resistance, short duration, and relatively high grain yields (Kauffman *et al*, 1984).

* **Correspondence to:** Ester C Casenave, Facultad de Agronomía y Agroindustrias, Universidad Nacional de Santiago del Estero, Avda Belgrano (s) 1912, 4200 Santiago del Estero, Argentina. Phone: (54-85) 213-074. Fax: (54-85) 224-919. E-mail: cachi@unse.edu.ar

When there is insufficient water and high temperature in the soil at sowing time, a major limiting factor to establish amaranth is poor seedling emergence. The germination percentage generally lowers with decreasing water potential, as determined in other species (Delaney *et al*, 1986; Romo & Haferkamp, 1987; Mian & Nafziger, 1994). Growers must often sow deeper than optimum level in order to protect seeds from high temperature and dehydration resulting from high rates of evaporation. Deep planting, however, has been found to delay or reduce emergence and vigor in many plant species (O'Connor & Gusta, 1994), while not having any effect in others (Qiu & Mosjidis, 1993 a). Highest amaranth emergence index and emergence percentage occur from 13 mm seeding depth at temperatures between 24 and 34°C, a large reduction in emergence index being observed when seeding depth is increased from 25 to 38 mm (Webb *et al*, 1987).

One way to improve emergence and seedling vigor, for deep sowing, is to use heavier or larger seeds because they have been found to increase percent emergence (Qiu & Mosjidis, 1993 b; Leishman & Westoby, 1994) or germination (Naylor, 1993). Nevertheless, exceptions have been reported (Hoy & Gamble, 1987; Radford & Key, 1993). The potential subsurface elongation and hence the potential maximum sowing depth for an amaranth seedling could be determined from its hypocotyl length. In common vetch, seed weight and maximum hypocotyl length are positively correlated (Qui & Mosjidis, 1993 b), while in oat Radford and Key (1993) found no significant correlation between seed weight and mesocotyl length, coleoptile length, or potential maximum sowing depth.

These studies were conducted in order to identify (i) whether germination differences were detectable from different water potentials and temperatures, and (ii) whether emergence differences were detectable from different cultivars, seed size and sowing depth.

The hypotheses for the present work were: i- water stress and high temperature decrease the germination of seeds, and ii- the larger seeds permit deeper sowing than small ones.

MATERIALS AND METHODS

Plant material

Samples of seeds of *Amaranthus cruentus* (cvs. *Don Armando* and *Don Guiem*), and *A. mantegazzianus* (cvs. *Don Juan* and *Don Manuel*), collected in La Pampa (1994), and obtained from INTA- Anguil Experimental Station, Argentina, were used in studies to determine percent seed germination and the effect of water stress and temperature studies. The same mentioned cultivars and *A. cruentus* cv. *Don Artaza*, collected in La Pampa (1995) and obtained from INTA-Anguil Experimental Station, Argentina, were used in studies to evaluate percent seed germination and the effect of seed size and sowing depth studies. The seeds from each cultivar were graded, *viz*: large > 1 mm, medium 1- 0.841 mm and small < 0.841 mm, and stored in paper bags at laboratory conditions. The weight frequency distribution was calculated for each grade. The seeds were not treated with any fungicides.

Percent seed germination

Five replicates of 100 seeds in 10 cm Petri dishes on a layer of filter paper were tested. The dishes were placed in a random arrangement, maintained at 25°C in the dark, and inspected daily over a period of 6 days. Those seeds which had germinated (defined as > 2 mm extension of the radicle) were counted and removed. The seeds left at the end of this period were considered ungerminated.

Effect of water stress and temperature on germination

Polyethylene glycol 6000 (PEG) was mixed with deionized water to get osmotic solution with water potentials ranging from 0 to -2 MPa in accord to Burlyn and Kaufmann (1973) method. For each level of water potential, one hundred seeds were placed on filter paper in a 10 cm Petri dish and 7 ml of solution was added. The high PEG solution volume to filter paper ratio used in this assay minimizes the change in water potential from PEG exclusion associated with filter paper substrates (Emmerich & Hardegree, 1990). Five replicates were placed in a dark germination room at four constant temperatures (25, 30, 35 and 40° C). The dishes were inspected daily, and the germination was evaluated as previously mentioned. Counts were discontinued when the number germinated per Petri dish did not change for 3 days. This study was duplicated with virtually identical results. A randomized complete design was followed for each experiment.

Effect of seed size and sowing depth on seedling emergence

Sowing took place on 21st November 1995, at the Santiago del Estero Experimental Field, located at 28° 03' S and 64° 15' W. Fifty seeds per grade were placed at a depth of 2, 4, and 6 cm in a randomized design with three repetitions and a plot size of 30 cm row. Soil are Entisol sandy loam. Soil tests at 0-30 cm depth indicated pH level of 7.7, organic matter of 2.34%, and EC of 2 dS m^{-1}. Maximum and minimum soil surface temperatures (at 2 cm) measured throughout the experiment were 43.5 and 21° C, respectively. Plots were watered as needed to maintain optimum moisture throughout the study. Maximum and minimum thermometers were placed at 2 cm depth. Seedling emergence counts were made daily, beginning with the initial appearance of seedlings and ending when no new seedling emerged. All emergence percentage data obtained were corrected according to germination percentage for each size grade. Average time to emergence (A_{te}) was calculated in accord to Brar and Stewart (1994). The seed was considered emerged when the shoot appeared above the soil level.

In order to determine the correlation between hypocotyl length and seed weight, thirty seeds of each cultivar were individually weighed and placed at a depth of 0.5 cm in pots filled with 1/3 soil, 2/3 perlite. All pots were maintained in darkness during 5 days at 25° C, and then the hypocotyl lengths were measured.

Statistical analyses

Analysis of variance (ANOVA) was used to evaluate the effects of treatments and their interactions on the response variables. Student-Newman-Keuls test at the 0.05 probability level was used for means separation. Regression analyses were applied to the relationships between seed weight *vs* hypocotyl length, and percent seed germination *vs* percent seedling emergence. All statistical analyses were performed using the statistical Statgraphic package.

RESULTS

Percent seed germination

Details on the genotypes used, percent seed germination, and proportions of each grade are given in Table I. Among the tested cultivars, four had approximately 10% of small size seeds while *Don Manuel* had more than 25%. Final germination percentage was not affected by seed size, except in *Don Manuel* where small seeds germinated less than medium or large ones.

Effect of water stress and temperature

Overall, seeds of all cultivars at any temperature ceased to germinate when exposed to -0.8 MPa water potential (Figs 1, 2 and 3) with the exception of *Don Manuel* (Fig 4). The pattern of results for the two cultivars of *A. cruentus* was similar, and a significant ($P < 0.05$) reduction in germination occurred at -0.4 MPa. Both cultivars of *A. mantegazzianus* were more tolerant as water potential decreased, but they became more sensitive to temperature. Optimum temperature was around 30° C in water stress. *Don Juan* was the most sensitive cultivar with a large reduction at 40°C, even in 0 MPa water

Table I

Details on the cultivars tested and traits of seed lots used.
Final germination values are averaged over five repetition of one hundred seeds.
(Small = < 0.841 mm; medium = 1-0.841 mm; large = > 1 mm)

		Year of collect			
		1994	1995		
Cultivars	Species	% Final germination	Seed size class	Proportion (% by weight)	% Final germination
Don Armando	*A. cruentus*	89	small	9.4	94 a
			medium	82.8	95 a
			arge	7.9	98 a
Don Guiem	*A. cruentus*	90	small	8.4	57 a
			medium	75.8	56 a
			large	75.8	60 a
Don Artaza	*A. cruentus*	-	small	11.8	96 a
			medium	82.2	99 a
			large	6.0	98 a
Don Juan	*A. mantegazzianus*	45	small	12.3	77 a
			medium	67.6	83 a
			large	20.1	90 a
Don Manuel	*A. mantegazzianus*	99	small	25.9	53 a
			medium	61.0	69 b
			large	13.1	73 b

Means within cultivar followed by same letter are not significantly different (P < 0.05).

conditions. *Don Armando*, *Don Guiem* and *Don Manuel* were practically temperature insensitive in water potentials from 0 to -0.4 MPa.

Effect of seed size and sowing depth

Emergence percentage average, across all cultivars and seed sizes, significantly decreased as sowing depth increased from 53% at 2 cm to 29% at 4 cm and 12% at 6 cm (Table II), and the effect of sowing depth was more significant for *Don Guiem*, *Don Juan* and *Don Manuel*.

Medium and large size seeds had significantly more emergence percent than small ones, but there was no difference between the seeds of medium and large size (Table III).

Emergence percentage for pooled medium and large size seeds decreased from 59 to 36 and 17% at 2, 4 and 6 cm depth, respectively (Table IV). The depth x cultivar interaction was significant. Emergence percentage was between 30 and 50% at all depths with the exception of *Don Armando* and *Don Artaza* at 2 cm depth (80-90%) and *Don Guiem*, *Don Juan* and *Don Manuel* at 6 cm depth (5-10%).

Emergence percentage at 2 cm sowing depth was significantly (P< 0.001) correlated with germination percentage in the laboratory (r= 0.87). The degree of correlation was inversely proportional to sowing depth ($r_{4\ cm}$ = 0.8, P< 0.001; $r_{6\ cm}$ = 0.56, P< 0.05). The relationship between seed weight and hypocotyl length has a correlation coefficient of 0.63 (P<0.001).

Differences in A_{te} (P< 0.001) were found among the sowing depths and seed sizes (Table V). Deep sowing significantly delayed emergence. Seedling from seeds 2, 4 and 6 cm deep required 3.3, 3.7 and 4 days to emerge, respectively. Seedlings from small, medium and large size seeds required 3.9, 3.6 and 3.4 days, respectively.

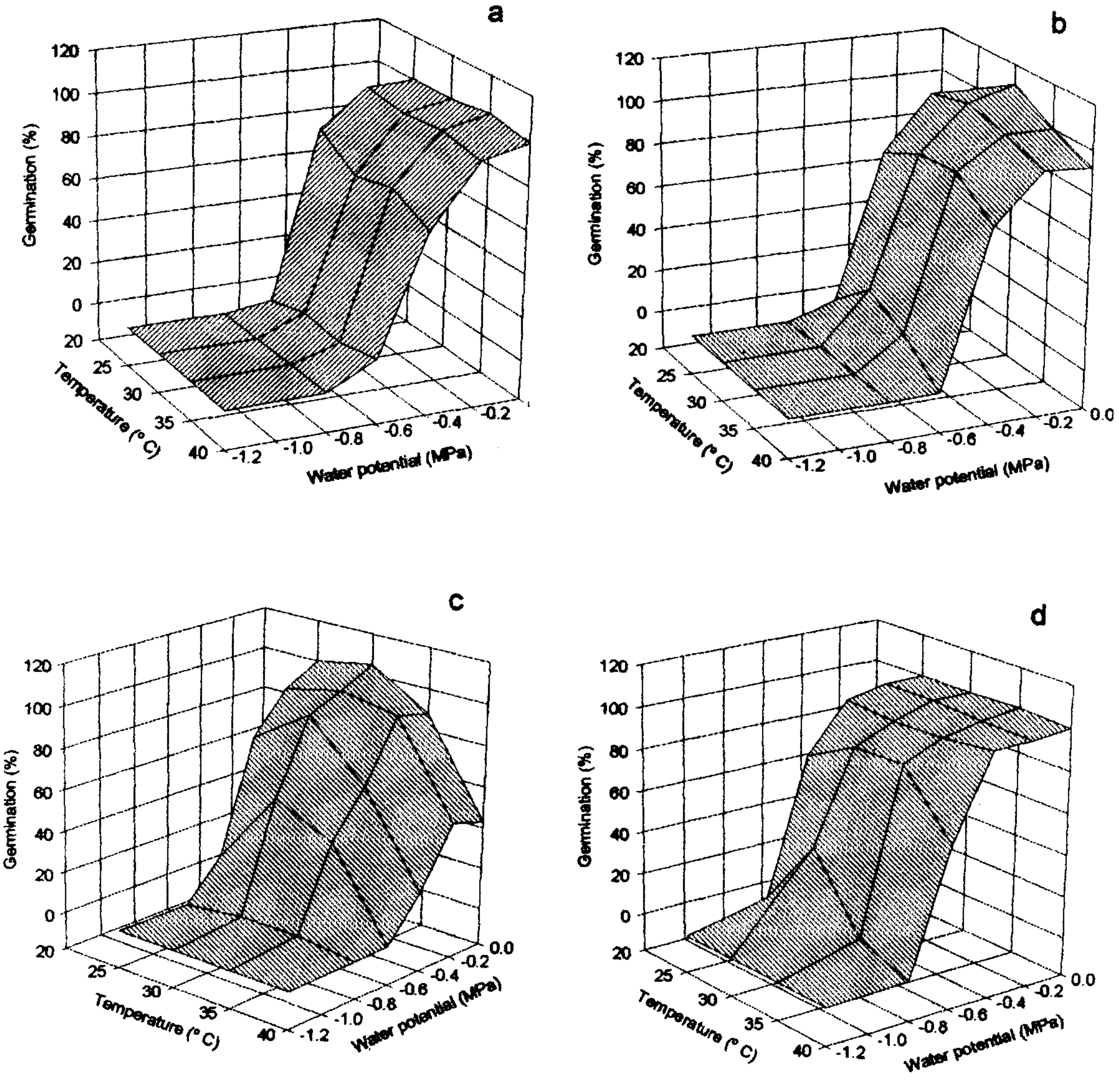

Fig 1. Germination of amaranth cultivars *Don Armando* (**a**), *Don Guiem* (**b**), *Don Juan* (**c**) and *Don Manuel* (**d**), as influenced by temperature and water potential. Germination is expressed as percentage to germination obtained at 25° C and zero water potential. Results are averages from five repetitions of one hundred seeds.

Table II

Emergence percentage of amaranth cultivars influenced by sowing depth. Emergence percentage values averaged over nine repetitions of fifty seeds.

Sowing depth	Cultivars					
(cm)	*Don Armando*	*Don Artaza*	*Don Guiem*	*Don Juan*	*Don Manuel*	Mean
2	79.7 a	77.4 a	40.1 a	40.6 a	29.0 a	53.4 a
4	33.8 b	45.6 b	23.6 b	24.3 ab	19.6 a	29.4 b
6	16.9 b	27.4 b	3.9 c	6.3 b	3.1 b	11.5 c

Means followed by same letter are not significantly different ($P < 0.05$).

Table III

Emergence percentage of amaranth cultivars influenced by seed size. Emergence percentage values averaged over nine repetitions of fifty seeds. (Small = < 0.841 mm; medium = 1-0.841 mm; large = > 1 mm).

	Cultivars					
Seed size	*Don Armando*	*Don Artaza*	*Don Guiem*	*Don Juan*	*Don Manuel*	Mean
Small	29.3 a	34.2 a	22.7 a	3.8 a	8.8 a	19.8 a
Medium	57.8 b	51.9 b	23.4 a	36.6 b	20.3 b	38.0 b
Large	43.2 ab	64.3 b	21.4 a	30.9 b	20.6 b	36.5 b

Means followed by same letter are not significantly different ($P < 0.05$).

Table IV

Emergence percentage (medium and large size pooled) of amaranth cultivars as influenced by sowing depth. Emergence percentage values averaged over six repetitions of fifty seeds. (Medium = 1- 0.841 mm; Large = > 1 mm).

	Sowing depth (cm)			
Cultivars	2,00	4,00	6,00	Means †
Don Armando	82 a	45 a	25 ab	51 a
Don Artaza	88 a	46 a	40 a	58 a
Don Guiem	34 b	28 a	6 b	22 b
Don Juan	56 b	36 a	10 b	34 b
Don Manuel	33 b	27 a	5 b	21 b
Means ††	59 a	36 b	17 c	

† Means followed by same letter are not significantly different ($P < 0.05$).
†† Means within sowing depth followed by same letter are not significantly different ($P < 0.05$).

Further analysis of a significant ($P < 0.05$) sowing depth x seed size interaction revealed that within each sowing depth large and medium size seeds emerged faster than small ones.

DISCUSSION

Of all five cultivars studied, only *Don Manuel* showed a decrease in germination. Small seeds of *Don Manuel* germinated less than medium and large ones. Seed size had no effect in germination for the other cultivars studied. Lafond and Baker (1986) and Mian and Nafziger (1994) found the same results in wheat. Similar results were reported by Wulff (1988) in *A. dubius*, who observed the same behavior in all but one of the families he assayed.

Although amaranths are species native to tropical and subtropical areas, due to their small seed size and therefore superficial sowing, implanting this species may imply some risk caused of dehydration and high temperatures in the top soil layer. Data from this study indicate that, with the exception of cv. *Don Juan*, temperature would not be a limiting factor. The behavior of cv. *Don Juan* agrees with the poor emergence observed by these authors in previous field assays. The optimum temperatures determined in the present study agree with those reported by Webb *et al* (1987) for the emergence of *A. hypochondriacus* (24-34°C) and by Gutterman *et al* (1992) for the germination of *A. caudatus* (35°C). Wulff (1988) found that different families of *A. dubius* respond in different manner. They respond in percent as well as in time of germination to increments in temperature between 25 and 38°C, with an optimum average temperature of germination of 38°C for the entire population. Therefore, different species, cultivars, and lines of amaranth respond to temperature in a different manner, probably due to both genetic variability and maternal environment effects. An important agronomic characteristic of amaranth is its broad temperature range for maximum germination.

Table V

Average time to emergence of amaranth cultivars influenced by sowing depth and seed size. Average times to emergence averaged over three repetitions of fifty seeds. (S = small = < 0.841 mm; M = medium = 1- 0.841 mm; L = large = > 1 mm).

	Average time to emergence (days) †												
	2				4				6				
Cultivars	S	M	L	Mean	S	M	L	Mean	S	M	L	Mean	Mean †
Don Armando	3.18	3.13	3.00	3.10 a	4.59	3.89	3.22	3.50 a	....	4.19	4.07	4.14 ab	3.55 a
Don Artaza	3.33	3.13	3.24	3.23 a	3.96	3.20	3.33	3.70 a	4.00	3.95	3.97	3.96 ab	3.53 a
Don Guiem	3.56	3.32	3.13	3.34 ab	4.36	3.73	3.53	3.81 a	....	4.17	3.50	3.83 ab	3.61 a
Don Juan	4.44	3.17	3.22	3.61 b	4.50	3.41	3.29	3.64 a	....	3.76	3.00	3.57 a	3.61 a
Don Manuel	3.87	2.98	3.31	3.38 ab	3.75	3.94	3.56	3.75 a	....	4.79	4.50	4.69 b	3.73 a
Mean ††	3.67 a	3.14 b	3.18 b		4.22 a	3.63 b	3.38 b		....	4.17 a	3.81 a		
Mean by sowing depth ††				3.53 a				3.67 b				4.01 c	

†Means followed by same letters are not significantly different ($P < 0.05$).
††Means within sowing depth followed by same letters are not significantly different ($P < 0.05$).

Elevated soil temperatures, like those observed in the present assay (up to 43.5°C), cause high dehydration rates. According to our results, water potentials lower than -0.4 MPa impose serious limitations to germination, in all cultivars with the exception of *Don Manuel*. These reductions in germination may be detrimental in semiarid conditions.

Sowing depth could be increased to avoid high soil temperatures and water stress. However, the greatest limitation in this sense would be the small seed of amaranth, with limited reserves to support germination and emergence of seedlings. In the present study, a marked decrease in emergence is observed, on average, when sowing is deeper then 2 cm. Similar results were reported by Webb *et al*, (1987) and Qiu and Mosjidis (1993 c).

Medium and large sized seeds had significantly better emergence than small ones. These results agree with the relationship observed between seed weight and hypocotyl length. Since most of the tested cultivars had only approximately 10% of small seeds, the size grading become unnecessary. This does not apply, however, to cv. *Don Manuel* for which small seeds represent more than 25% and germinate lower than medium and large ones.

Taking into account that emergence percent as a function of sowing depth varied according to cultivar, one should consider that for cvs. *Don Armando* and *Don Artaza*, those with the best behavior at greatest depth level, emergence percent of approximately 50% could be obtained by duplicating sowing rate at 4 cm, and even 6 cm depth for these two cultivars.

The high correlation observed between the emergence percent at 2 cm sowing depth in the field and germination percent in the laboratory would indicate that emergence in the field at 2 cm sowing depth and adequate soil water conditions can be estimated from germination percent. Brar and Steward (1994) found the same relationship. Correlation declined as sowing depth increased. This weak relationship implies that depth imposes limitation on emergence.

As previously documented for other species (Qiu & Mosjidis, 1993a; O'Connor & Gusta, 1994) the average time to emergence increased with sowing depth or as seed size decreased. O'Connor and Gusta (1994), working with seeds of flax, and Oladiran and Mumford (1990), working with *A. gangeticus* and *A. hybridus*, also obtained that the time of 50% germination was lowest for the cultivar with largest seed size. However, Hoy and Gamble (1987) reported that large sized soybean seeds generally emerged more slowly than seeds from the other size classes, and Qiu and Mosjidis (1993 a) found that the main effect of common vetch seed weight was not significant. These differences in A_{te}, among seed sizes, may be large enough to be of practical importance, especially in arid environments with fast-drying soil surface.

In conclusion, data from this experiment show that even with favorable soil moisture, the sowing amaranth deeper than 2 cm delays and decreases emergence. High soil surface temperature may not be limiting factor on seedling emergence if soil water conditions are adequate. Nonetheless, cultural practices that extend the period of high soil water potentials and seeds of a size larger than 0.8 mm should be used to improve the establishment of amaranth. Deeper sowing may be practical if seeding rates are adjusted to compensate for reduced emergence percent associated with sowing depth.

REFERENCES

BURLYN EM, KAUFMANN MR (1973) The osmotic potential of polyethylene glycol 6000. Plant Physiol 51: 914-916

BRAR GS, STEWART BA (1994) Germination under controlled temperature and field emergence of 13 Sorghum cultivars. Crop Sci 34: 1336-1340

DELANEY RH, ABERNETHY RH, JOHNSON DW (1986) Temperature and water stress effects on germination of Ruby Valley pointvetch (*Oxytropis riparia* Litv.). Crop Sci 26:161-164

EMMERICH WE, HARDEGREE SP (1990). Polyethylene glycol solution contact effects on seed germination. Agron J 82:1103-1107

GUTTERMAN Y, CORBINEAU F, CÔME D (1992) Interrelated effects of temperature, light and oxygen on *Amaranthus caudatus* L. seed germination. Weed Res 32: 111-117

HOY DJ, GAMBLE EE (1987) Field performance in soybean with seeds of differing size and density. Crop Sci 27: 121-126

KAUFFMAN CS, BAILEY NN, VOLAK BT, WEBER LE, VOLK NR (1984) Amaranth grain production guide. New Crops Department. Rodale Research Center. Rodale Press, Inc. RRC/NC-84-6

LAFOND GP, BAKER RJ (1986) Effects of temperature, moisture stress, and seed size on germination of nine spring wheat cultivars. Crop Sci 26: 563-567

LEISHMAN MR, WESTOBY M (1994) The role of seed size in seedling establishment in dry soil conditions-experimental evidence from semi-arid species. J Ecol 82: 249-258

MIAN MAR, NAFZIGER ED (1994) Seed size and water potential effects on germination and seedling growth of winter wheat. Crop Sci 34: 169-171

NAYLOR REL (1993) The effect of parent plant nutrition on seed size, viability and vigour and on germination of wheat and triticale at different temperatures. Ann Appl Biol 123: 379-390

O'CONNOR BJ, GUSTA LV (1994) Effect of low temperature and seeding depth on the germination and emergence of seven flax (*Linum usitatissimum* L.) cultivars. Can J Plant Sci 74: 247-253

OLADIRAN JA, MUMFORD PM (1990) The longevity of large and small seeds of *Amaranthus gangeticus* and *A. hybridus*. Seed Sci Technol 18: 499-506

QIU J, MOSJIDIS JA (1993a) Influence of seed weight and planting depth on common vetch establishment and growth. Field Crops Research 33: 353-366

QIU J, MOSJIDIS JA (1993b) Relationships among maximum hypocotyl length, seed weight, and emergence in sericea lespedeza. Agron J 85: 995-998

QIU J, MOSJIDIS JA (1993c) Genotype and planting depth effects on seed-ling vigor in sericea lespedeza. J Range Manage 46: 309-312

RADFORD BJ, KEY AJ (1993) Temperature affects germination, mesocotyl length and coleoptile length of Oats genotypes. Aust J Agric Res 44: 677-688

ROMO JT, HAFERKAMP MR (1987) Forage Kochia germination response to temperature, water stress, and specific ions. Agron J 79: 27-30

WEBB DM, SMITH CW, SCHULZ-SCHAEFFER J (1987) Amaranth seedling emergence as affected by seeding depth and temperature on a thermogradient plate. Agron J 79: 23-26

WULFF RD (1988) Intraspecific variation in germination requirements and growth in *Amaranthus dubius*. Amer J Bot 75:1307-1312