Effect of Seed Vigour and Mechanical Impedance on Growth of Sorghum (*Sorghum bicolor*, L Moench) Seedlings

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Abstract

This study investigated the effect of seed vigour on seedling response to soil mechanical impedance (MI) during establishment. Unaged and artificially aged pre-germinated seeds were planted in compacted soil and in vermiculite for 8 days. Penetration resistance was 1.1 ± 0.05 MPa in compacted soil and 0.03 MPa in vermiculite filled cylinders. The test crop was sorghum cultivar IGSV-112. Treatments were replicated six times in soil and five times in vermiculite. Parameters studied include time to seedling emergence, root and shoot growth. Seedlings from aged seed took significantly longer (122 hours) to emerge compared to those from high vigour seed (80 hours) but only in compacted soil. Emergence was significantly early in vermiculite where irrespective of seed vigour, seedlings emerged within 55 to 57 hours after planting. Unaged seed had significantly more root mass but only in compacted soil. Treatments had no effect on the number of leaves per seedling. Other root and shoot parameters were affected by MI but not seed vigour. We conclude that a combination of mechanical impedance and low seed vigour cause poor crop establishment. Establishment is likely to be even worse under hostile growing conditions in the semi arid tropics where sowing of low vigour seed is very common, and planting rains are erratic and hence moisture stress becomes an added problem.

Keywords: Seed vigour, Mechanical impedance, Seedling growth, Sorghum

Introduction

Different seed lots passing the viability test, whilst all with acceptable and similar high percentages of laboratory germination can sometimes show considerable differences in field emergence (Perry,1972). It has been largely the absence of a consistent relation between germination in the laboratory and emergence in the field that has been responsible for the development of the concept of seed vigour (Powell and Matthews, 1979). The fundamental requirement of a seed lot is that the seeds germinate and do so completely, the quicker the better, and the more unfavourable conditions under which they can do this the better (Woodstock, 1969). Seed which satisfies these criteria has come to be termed high vigour seed. Perry (1972) defined seed vigour as a physiological property determined by the genotype and modified by the environment, which governs the ability of the seed to produce a seedling rapidly in a soil, and the extent to which that seed tolerates a range of environmental factors. Hartmann and Kester (1968) referred to the vigour phenomenon as seed vitality, or germinating power which could be represented by the germination rate. According to Hartmann and Kester, in seeds of low viability, a low germination percentage and a low rate of germination are often associated. A reduction in seed viability and vigour, may result from incomplete seed development on the mother plant, injuries during harvest, improper processing and storage, or ageing (Hartmann and Kester, 1968). With long storage, reduced viability is usually preceded by a period of declining vitality (Toole *et al.*; 1956). Seed deterioration leading to seed death is a gradual culminative process and only when certain critical parts of the seed

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are affected is there a loss in viability (Woodstock, 1969). Vigour therefore, starts to decline before viability and seed lots with similar viability may differ remarkably in vigour.

Several studies have reported that aged (low vigour) seeds are more sensitive to stress factors than unaged (high vigour) seeds during germination (Perry, 1970; Naylor, 1989; Gurmu and Naylor, 1990). Water stress is factor that has been most commonly studied in terms of its effect on germination phenomena in relation to seed vigour (Bewley and Black; 1982; Marshall and Naylor, 1984, 1985; Gurmu, 1991). In the field, manifestation of differences in vigour depend on the interaction between the seed and environmental factors. Most often, several of these factors such as soil strength, matric suction and temperature vary simultaneously. Thus, difficulty arises in determining as to which among these factors germinating seeds could be responding to. Soil mechanical impedance and water stress are the main stress factors influencing germination of seeds under traditional agriculture in the semi-arid tropics (SAT). Recent studies (Naylor and Gurmu, 1990) have shown that seed viguor influences the response of germination to water stress. On the other hand, apart from general statements in the literature (that aged seeds are more sensitive than unaged ones to stress factors), we are not aware of any studies done to determine how aged seeds respond to mechanical impedance. The purpose of the present study was to test the hypothesis that during germination, seedlings from aged seed respond to mechanical impedance in the same manner as those from unaged seed.

Materials and methods

Properties and preparation of growth media

A sandy clay loam (Carpow Series) top soil (0-10 cm) was used as an impending growth medium. The soil contained 21 g kg^{-1} organic matter and particle size distribution with 206 g kg^{-1} clay (µm), 180 g kg^{-1} silt, and 614 g kg^{-1} sand (60-2000 µm). Soil pH was 6.7. Control plants were grown in vermiculite. A dilute nutrient solution as formulated by Hackett (1986) was used to moisten the growth media. The nutrient solution was prepared using deionized water. The growth medium was packed into transparent perspex cylinders 5 cm internal diameter and 30 cm high. A black polythene sheet completely covered each cylinder to prevent light from interfering with root growth. The bottom of each cylinder was wrapped with a J-cloth supported by a wire mesh held in place by insulating tape.

Seed material

The sorghum seeds cultivar ICSV-112 was supplied by the International Crop Research Institute for Semi - Arid Tropics (ICRISAT), Hyderabad, India. Seeds whose weight fell within a range of ±1 s.d. of the mean (26 mg) weight were used in the study. The unaged seed had a laboratory germination of 100%. Aged seed was obtained by artificially ageing fresh seed following the controlled deterioration (CD) procedure (Mathews, 1980). The procedure consists of laboratory germination which has been preceded by periods of exposure to high temperature at specified levels of seed moisture content. Seed lots with a low final germination percentage after CD are said to be of low vigour and identified as of low planting and storing value (Naylor, 1989). In the reported study, seed samples were allowed to imbibe to a moisture content of 0.21 g g^{-1} then heat sealed in aluminium foil packets followed by incubation in a water bath at 45 °C for 4 days. After the ageing treatment, the low vigour seed had a laboratory germination of 74%.

Packing of cylinders

Weighed air-dry soil of pre-determined moisture content was placed in a mixing bowl and sufficient nutrient solution was added to bring it to field capacity (0.22 g g-1 moisture content, approximately 10 kPa matric suction) as previously determined. Following thorough mixing, the moist soil was made to pass through a 6.35 mm sieve. Aggregates which were retained on a 2 mm sieve were used in the study. The soil was packed moist in perspex cylinders to a bulk density of 1.45 Mg m^{-3}. To obtain uniform soil strength throughout the cylinder, packing was in 2 cm increments. Soil material calculated to fill each 2 cm height increment to the desired bulk density was weighed and packed. All cylinders were packed to within 4 cm of the top. Control cylinders were loosely packed with vermiculite moistened with nutrient solution at a ratio of 1 kg vermiculite to 2 litres of solution previously determined to correspond to field capacity. Penetration resistance (PR) was measured using a penetrometer. The penetrometer needle used had a 2mm diameter cone with a 30 semi-angle and a recessed shaft. Penetration resistance was measured in trial setups (cylinders packed to required bulk densities and moisture contents) to get an indication of what penetration resistance the roots and shoots would experience. In compacted soil, penetration resistance (PR) was 1.1 ± 0.05 MPa at planting. In vermiculite filled cylinders, PR was 0.03 MPa.

Pregermination of seeds

Seeds were pre-germinated on moist filter paper and a temperature of 25 °C. Excess seeds were pre-germinated to ensure an adequate supply of germinated seeds at planting. Slow germinating aged seeds were started off earlier in the pre-germination process so that seedlings would be at the same stage as those from fresh seeds at planting. Pre-germination trials had been performed to determine the time schedule necessary to achieve this objective. At planting, fresh and aged seeds had been wetted for 41 and 63 hours respectively.

Planting procedure

At planting, radicle lengths were 6 mm on average. Individual radicle lengths were measured using vernier callipers. A small hole corresponding to the length of the radicle was made in the soil or vermiculite at the centre of the cylinder using a rigid wire. The radicle was lowered into the hole and the seed rested on the surface. Loose soil or vermiculite was then covered over the seed to 3 cm depth. A layer 10 mm of black polystyrene beads was placed over the growth media to reduce evaporation.

Environmental conditions

After planting, seeds were placed in a partially controlled environment. A timer automatically switched on lights at 7 am and off at 7 p.m. to simulate a 12 hour photoperiod. Every other day, control cylinders received 20 ml of nutrient solution as they tended to dry out very fast. Oxygen concentration in soil was 18.1 % at planting time which was adequate since it becomes limiting at concentrations of below 10% (Grable and Siemer, 1968). The oxygen concentration was measured with a micro-electrode meter (type A 1302, Strathkelvin Instruments, Glasgow) in air saturated solution. Ambient growth room temperature was recorded using a thermograph. A maximum-minimum thermometer attached to the thermometer cage served as a check. A digital thermocouple sensor (type K) was used to read temperature at specified depths in the growth media. A favourable temperature is a requirement for germination. Optimum temperatures for growth of sorghum are 27 °C to 30° C (Arnon, 1972). An air conditioner installed in the growth room kept temperatures below 27 °C when lights were switched on.

Plant measurements

Cylinders were inspected daily for signs of emergence by temporarily removing the black plastic sheet. After 8 days, cylinders were individually harvested to measure: root and shoot lengths; fresh mass; number of leaves; number of lateral roots; thickness of the main axis (measured 5 mm from the apex). A travelling microscope was used to measure root thickness.

Experimental layout and analysis of data

There were (a) two seed vigour categories, unaged and artificially aged seeds and (b) two levels of mechanical impedance, compacted soil and vermiculite. Unaged and aged seeds were planted both in soil and in vermiculite. Each treatment was replicated six times in soil and five times in vermiculite. All statistical analyses were performed using a computer software- Statigraphics Version 5 from Statistical Graphics Corporation, US.

Results and Disussion

Environmental conditions

Daily mean temperature at planting depth fluctuated between 24.6 °C and 29.2°C during the study period. Overall, mean daily temperature was 26.6±0.6C. Penetration resistance (PR) in compacted soil increased from 1.1± 0.05 MPa at planting to 1.4± 0.06 MPa at harvest. In vermiculite, PR was still 0.03 MPa. At harvest, soil moisture content had fallen to 0.19 g g^{-1} from 0.22 g g^{-1} (corresponding to matric suctions of 10 kPa and 22 kPa respectively).

Seedling emergence

Time to emergence as affected by mechanical impedance (MI) and seed vigour is presented in Table 1. Seedlings emerged significantly earlier (P=0.05) from vermiculite than from compacted soil. The above was true both for aged and unaged seed. Averaged over vigour categories, emergence was after 101 and 56 hours from compacted soil and from vermiculite respectively. In vermiculite, time to emergence was not affected by seed vigour. Emergence of seedlings from aged seeds and from compacted soil, was significantly (P=0.05) delayed by 42 hours compared to seedlings from unaged seeds grown in vermiculite.

Table1: Time (h) to emergence as affected by mechanical impedance and seed vigour (values are: mean ±se (CV%))

Seed type	Impeded	Unimpeded	Test of significance between MI
Aged seed	121.75 ± 18.6 (37)[b]	57 ± 2 (8)[a]	**
Unaged seed	79.67 ± 3.3 (10)[a]	55 ± 0 (0)[a]	**

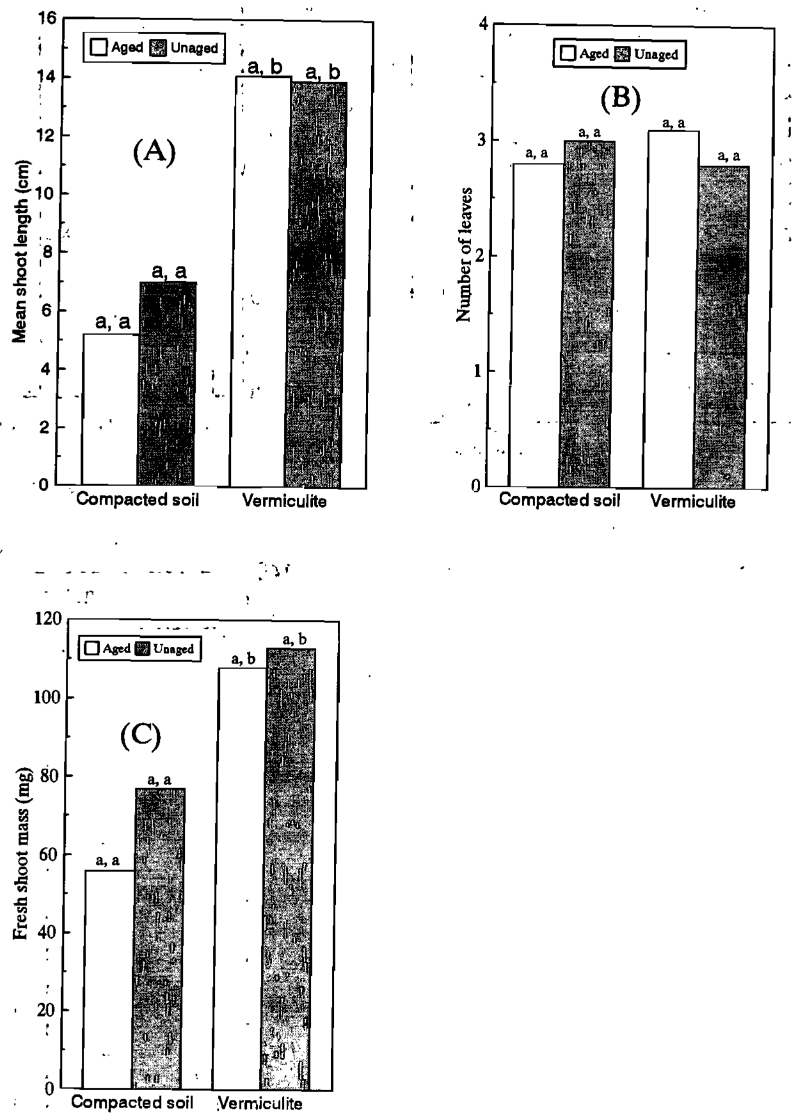
In each column, values sharing the same letter are not significantly different (P=0.05)

Seedlings in compacted soil took significantly longer to emerge compared to those in vermiculite despite the seed having been covered with loose soil at their planting depth offering little more impedance to the shoot than the control. This means that MI to the root system slowed down shoot growth prior to emergence. Root-shoot communication of the nature reported by other workers (Dawkin *et al.*, 1983; Masle and Passioura, 1987; Sharp, 1990) was possibly involved. The delay in emergence under MI for seedlings from aged seeds was 1.8 days compared to seedlings from unaged seeds. The importance of having fast emerging seedlings was demonstrated by Weaich (1993) in a hardsetting soil using a maize crop.

Shoot parameters

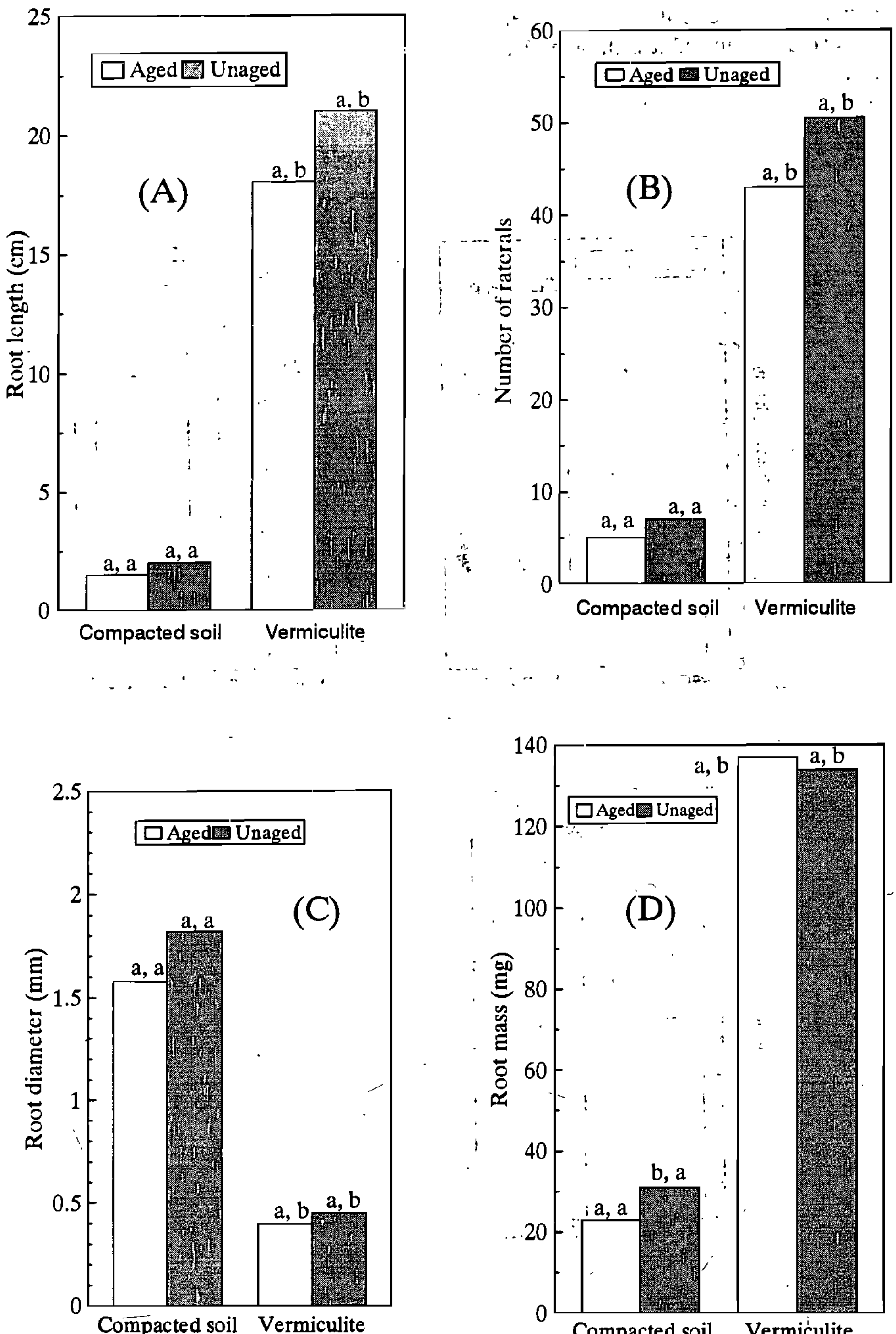
Figure 1 shows the shoot parameters as affected by different treatments. Seedlings had significantly (P=0.05) longer shoots in vermiculite (13.8 cm) than in compacted soil (5.9 cm). Seed vigour had no significant effect on shoot lengths under both levels of MI. Similarly, the number of leaves produced by seedlings was unaffected by any of the treatment factors. At harvest, all seedlings had three leaves on the average. Seedlings grown in vermiculite, accumulated significantly (P=0.05) more fresh shoot mass (109.6 mg) than those growing in compacted soil (64.9).

Significantly longer shoots in vermiculite compared to those from compacted soil might have been due to the significant difference in the time to emergence. Shoot lengths for aged seeds in vermiculite equalled those from its unaged seeds. In addition, the number of leaves produced by the seedlings was unaffected by the treatments. Seedlings had three leaves at harvest in all treatments including the control. These features indicate that seed vigour may not affect subsequent plant growth after germination and emergence have occurred. This is contrary to the popular view (Perry, 1972) that the influence of seed vigour may persist throughout the life of the plant. A chain of events resulted in less shoot mass being accumulated by seedlings growing in compacted soil compared to those in vermiculite. Delayed emergence resulted in shorter time of growth before harvest. Consequently, shoots were shorter and had accumulated less mass by harvesting time.



Note: Values that differ significantly ($P = 0.05$) are indicated by different letters. The first letter compares seed vigour for a given treatment and the second compares treatments for a given seed vigour

Figure 1: Means of shoot lengths (A), number of leaves (B), and shoot mass (C), as affected by mechanical impedance and seed vigour



Note: Values that differ significantly (P = 0.05) are indicated by different letters. The first letter compares seed vigour for a given treatment and the second compares treatments for a given seed vigour

Figure 2: Means of root lengths (A), number of laterals (B), root diameter (C), and fresh root mass (D), as affected by mechanical impedance and seed vigour

Root parameters

The root parameters as affected by MI and seed vigour are shown in Figure 2. Seedlings growing in vermiculite developed significantly (P=0.05) longer roots than those in compacted soil. Roots were 13 to 14 times longer in vermiculite than in soil. Averaged over seed vigour, root lengths were 1.4 and 19.5 cm in soil and in vermiculite, respectively. Seed vigour had no significant effect on root lengths neither for seedlings growing soil or in vermiculite. The number of lateral roots produced in soil were 12 to 14% of the numbers in control seedlings (Figure (B)). Averaged over seed vigour, seedlings had 10 and 42 laterals in compacted soil and in vermiculite respectively. Seed vigour had no significant effect on the number of lateral roots developed by seedlings neither in soil nor in vermiculite.

Seedlings growing compacted soil developed significantly (P=0.05) thicker radicles than those in vermiculite (Figure 2 (C)). Radicles were three times thicker in seedlings subjected to mechanical impedance than those in the control. Seed vigour had no significant (P=0.05) effect on the thickness of radicles developed in the control or in seedlings subjected to MI.

Seed vigour significantly (P=0.05) affected root mass but only under MI where root mass was 30.83 mg for seedlings from unaged compared to 22 mg from aged seeds. Fresh root mass was significantly greater (P=0.05) under unimpeded compared to impeded conditions. Compared with unimpeded roots, root mass under MI was only 16 and 23% for aged and unaged seeds respectively.

The reduction in root growth and the number of laterals produced; including the increase in root thickness under mechanical impedance, have been reported also from other studies. Studies by Eavis (1967) on the effect of penetration resistance on the morphology and growth of pea radicle found that, (i) root length was approximately inversely proportional to penetration resistance and that (ii) the radicle enlarged radially with increasing penetration resistance. He associated the enlargement with an increase in diameter of the cortical cells.

Possible explanations as to why fewer lateral roots were produced under MI include shorter radicles on which only a small number of laterals could develop (Tsegaye and Mullins, 1994). The overall consequence of having fewer laterals, was a significant reduction in root mass.

Roots did not extend beyond 2 cm in compacted soil. Under field conditions, seedling growth and adequate water supply to roots would be difficult since the upper surface of the soil is subject to fluctuations in temperature and water supply. A combination of water stress and mechanical impedance would normally reduce or prevent establishment.

Conclusion

Aged seed significantly delayed emergence and especially in seedlings subjected to MI. The accumulation of root mass was also significantly reduced in the same treatments. A combination of MI and low vigour seed is thus a cause of poor crop establishment. Establishment is likely to be even worse in the SAT where sowing of low vigour seed is very common, and planting rains are erratic and hence moisture stress becomes an added problem.

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References

Arnon, I., 1972."Crop Production in Dry Regions", Volume II: Systematic Treatment of the Principal Crops. Leonard Hill, London.

Bewley, T.D. and Black, M., 1982. "Physiology and biochemistry of seeds in relation to germination", Volume 2, Springer-Verlag, New York. pp. 313-334.

Dawkin, T.C.K., Roberts, J.A. and Brereton, J.C. 1983. Mechanical impedance and root growth - The role of endogenous ethylene. In: Jackson, M.B. and Stead, A.D. (Eds), *Growth Regulators in Root Development*. Monograph British Plant Growth Regulator Group, pp 55-71.

Eavis, B.W. 1967. Mechanical impedance to root growth. Agricultural Engineering Symposium, Silsoe. Paper4/F/39, 1-11.

Grable, A.R. and Siemer, E.G. 1968. Effects of bulk density, aggregate size, and soil water suction on oxygen diffusion, redox potentials, and elongation of corn roots. *Soil Sci. Soc. Amer. Pro. 32*, 180-186.

Hackett, C., 1986. A study of the root system of barley. I. Effects of nutrition on two varieties. *New Phytol.* 67, 287-299.

Hartmann, H.T. and Kester, D.E., 1968. Plant Propagation: Principles and Practices, (2nd Ed.), Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Marshall, A.H. and Naylor, R.E.L. 1984. Reasons for poor establishment of direct reseeded grassland. *Ann. Appl.Bot. 105*, 87-96.

Marshall, A.H. and Naylor, R.E.L. 1985. Ryegrass seed-water relationships. *Seed Sci. Tech. 13*, 829-845.

Masle, J. and Passioura. J.B. 1987. The effect of soil strength on the growth of young wheat plants. *Austr. J. Plant Physiol. 14*, 643-656.

Mathews, S. 1980. Controlled deterioration: A new vigour test for crop seeds. In: Hebblethwaite, P.D. (Ed), *Seed Production*. Butterworths , London. pp.647-670.

Naylor, R.E.L. 1989. Analysis of the differences in germination of seedlots of perennial ryegrass in response to artificial ageing. *J. Agric. Sci., Cambr 112*, 351-357.

Naylor, R.E.L. and Gurmu, M. 1990. Seed vigour and water relations in wheat. *Annals of Appl. Biol. 117*, 441-450. Perry, D.A. 1970. The relation of seed vigour to field establishment of garden pea cultivars. *J. Agric. Sci., Cambr 74*, 343-348.

Perry, D.A. 1972. Interacting effects of seed vigour and environment on seedling establishment. Panel discussion: Pre-sowing seed treatments. In: Heydecker, W. (Ed), *Seed Ecology*, 19th Easter School in Agricultural Science: Univ. of Nottingham. pp. 311-323.

Powell, A.A. and Matthews, S., 1979. The influence of testa condition on the imbibition and vigour of pea seeds. *J. Exp. Bot., 30, 193-197.*

Sharp, R.E. 1990. Comparative sensitivity of root and shoot growth and physiology to low water potential. In: Jackson, M.B. and Stead, A.D. (Eds) *Growth Regulators in Root Development*, . Monog. No. 21. British Plant Growth Regulator Group.

Toole, E.H., Hendricks, S.B., Borthwick, H.A. and Toole, V.K., 1956. Physiology of seed germination. *Ann. Rev. Plant Physiol., 7, 299-324.*

Tsegaye, T. and Mullins, C.E., 1994. Effect of mechanical impedance on root growth and morphology of two varieties of pea (Pisum sativum L.). *New Phytol., 126, 707-713.*

Weaich, K. 1993. Pre-emergent shoot growth of maize (Zea mays L.) under high soil temperature and strength conditions. Ph.D. Thesis. University of New England, Australia.

Woodstock, L.W., 1969. Seedling growth as a measure of seed vigour. Proceedings of the International Seed Testing Association (ISTA), 34, 273-280.