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Title Factors affecting the Germination and Establishment of Monogerm Sugar Beet.

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FACTORS AFFECTING THE GERMINATION AND
ESTABLISHMENT OF MONOGERM SUGAR BEET

by

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CONTENTS

	<u>Page</u>
LIST OF FIGURES	(i)
1. INTRODUCTION	1
2. REVIEW OF LITERATURE	3
2.1 Introduction to Review	3
2.2 Seed production and seed treatments	3
2.2.1 Introduction	3
2.2.2 A brief history of monogerm seed	4
2.2.3 Sugar beet breeding	4
2.2.4 Varieties	5
2.2.5 Commercial seed production	5
2.2.6 Post harvest treatments	6
2.2.7 Pelleting	7
2.2.8 Alternative seed treatments	8
2.3 Factors affecting germination	12
2.3.1 Introduction	12
2.3.2 Seed storage	12
2.3.3 Germination tests	13
2.3.4 Effects of inhibitors on germination	14
2.3.5 The germination process and the involvement of air and water	15
2.4 Factors affecting the establishment of beet	19
2.4.1 Introduction	19
2.4.2 Plant population	20
2.4.3 Cultivation and seed bed preparations	21
2.4.4 Drilling	21
2.4.5 Field emergence	23
2.4.6 Predicting sugar beet emergence	24
2.4.7 The effect of seed size on emergence	26
2.4.8 Other emergence factors	27

CONTENTS (Contd)

	<u>Page</u>	
2.5	Alternative methods of establishing beet	29
2.5.1	Transplanting	29
2.5.2	Autumn sowing	30
2.5.3	Conclusion	30
3.	EXPERIMENTS	31
3.1	Materials and Methods	31
3.1.1	Description of seed lots	31
3.1.2	Seed characteristics	31
3.1.3	Germination and emergence tests	32
3.1.4	The effect of water-soluble inhibitors on cress seed germination	36
3.2	Results	36
3.2.1	Seed characteristics	36
3.2.2	The germination experiments	38
3.2.3	The emergence test	57
3.2.4	The effect of water-soluble seed extracts on cress seed germination	57
3.3	Discussion	60
3.3.1	Germination tests at standard temperatures and 7.5°C with untreated seed	60
3.3.2	Seed characteristics	63
3.3.3	Germination tests with treated seed	64
3.3.4	The emergence test	69
3.3.5	Conclusion	70
4.	GENERAL DISCUSSION: THE POTENTIAL OF SEED TREATMENTS TO IMPROVE FIELD EMERGENCE	71
5.	SUMMARY	76
6.	CONCLUSIONS	77
7.	REFERENCES	78

LIST OF FIGURES

	<u>Page</u>
1. The relationship between seed weight and true seed weight for Seed Lot 1	39
2. The relationship between seed weight and true seed weight for Seed Lot 2	40
3. The relationship between seed weight and true seed weight for Seed Lot 3	41
4. The relationship between seed weight and true seed weight for Seed Lot 4	42
5. The relationship between seed weight and true seed weight for Seed Lot 5	43
6. Germination pattern of five seed lots under standard germination test conditions	47
7. Germination pattern of five seed lots under low temperature conditions (constant 7.5°C)	49
8. Germination pattern of three seed lots (advanced in water) under standard germination test conditions	
9. Germination pattern of five seed lots (advanced in water) under low temperature conditions	53
10. Germination pattern of five seed lots (with GA ₃ , solution in place of distilled H ₂ O in the petri-dishes) otherwise under standard germination test conditions	55
11. Germination pattern of three seed lots (advanced in GA ₃ solution) under standard germination conditions	56

1. INTRODUCTION

The final yield of sugar obtained from the sugar beet crop (Beta vulgaris L.) is determined by many factors, including: the length of the growing season, the incidence of diseases and pests, and the prevailing weather conditions (Biscoe, Draycott & Jaggard 1980). These factors have a direct or indirect effect on photosynthesis and consequently the amount of assimilate translocated to the roots. It is therefore the duration of the leaves which can produce assimilate (i.e. excluding excessively shaded and diseased leaves) that determines the maximum potential yield.

The actual yield obtained is determined by the amount of solar radiation intercepted and utilised by the leaf canopy over the - whole growing season. Scott, English, Wood & Unsworth (1973) have shown that a good linear relationship between sugar yield and both total incident and intercepted radiation exists.

The grower cannot of course control the amount of incident radiation but his objective must be to ensure as much of it is intercepted as possible. However under the ambient Spring soil temperatures of the U.K., sugar beet is very slow in emerging and establishing, and complete leaf coverage does not occur until July.

It was estimated by Scott & Jaggard (1978) that just over 50% of the total radiation is intercepted by crops in the ground between April and October. The rest strikes bare ground and is wasted.

There is clearly considerable scope for improving the efficiency of interception by achieving full leaf coverage sooner. It is in fact the slow rate of growth over the early part of the season that results in late leaf coverage and poor

radiation interception. Growers would welcome any feasible method of improving the early growth of the crop.

The objective of this thesis is to discuss the early stages of sugar beet growth and the various problems affecting establishment that exist with sugar beet seed, both in its production and performance in the field.

2. REVIEW OF LITERATURE

2.1 Introduction to review

The literature reviewed in this thesis considers three main areas, namely seed production, seed germination and field establishment. Standard methods and various alternative procedures for treating and testing beet seeds are firstly described and discussed and then related to field performance. It will be explained why establishment is still a problem in modern crops and why seed quality is of major importance.

In the review and thereafter whole fruits will be referred to as seeds, embryos as true seeds, and the rest of the fruit as the seed coat and the ovary cap (which is considered to be part of the seed coat), as the seed cap unless otherwise indicated.

2.2 Seed production and seed treatment

2.2.1 Introduction

This section is mainly concerned with monogerm sugar beet seed as multigerm seeds are no longer used for sugar production.

The considerable difficulties encountered in breeding and producing good quality monogerm seed are outlined and modern varieties described.

As freshly harvested seed is of poor quality and cannot be used successfully in practice because it contains both empty seeds and multigerms the various processing procedures and alternatives are described in detail. The limitations of certain treatments are considered, as perfect seed lots cannot be produced on a commercial scale.

2.2.2 A brief history of monogerm seed

The advantages of seeds containing only one true seed were first realised in the early 1900's, but early Breeding Projects in the U.S.A. failed to produce plants with more than 75% single flowers. The idea was abandoned until the 1930's when it was re-investigated in Russia. Plants with complete monogermity were produced but other growth features were poor and commercial varieties were not available until the 1960's due to severe breeding difficulties (Orlovskii 1957) & (Savitsky 1952). Today however, monogerm varieties have almost completely replaced multigerms.

2.2.3 Sugar beet breeding

Breeding sugar beet is complicated by its biennial habit which makes the period taken to produce new varieties much longer than with most other species. It is also an open or out pollinating crop which makes uniformity difficult to achieve. However, several methods of breeding can be used, e.g. mass selection where the largest and best shaped roots are selected to produce seeds which are planted and the best progeny selected for further seed production. The method can be used to reliably improve existing varieties when crossed with other plants with desirable characters. Other methods used singly or in various combinations include hybridization polyploidy and male sterile lines. Some of the main objectives in sugar beet breeding are:-

- 1 The monogerm character for commercial crops but multigerm pollinators are still necessary.
- 2 High sugar yield per ha as the best compromise between root yield and sugar %.
- 3 Low bolting tendency.
- 4 Good germination and early growth.

- 5 High purity.
- 6 Good root shape.
- 7 Disease resistance to virus yellows & downy mildew.

(Ellerton 1978).

2.2.4 Varieties

All nine varieties on the recommended list are genetic monogerm and produce over 90% single plants after processing (NIAB 1980). All modern varieties produce similar yields in trials, and have sugar contents over 17%. There are varietal differences in downy mildew resistance, bolting susceptibility, size of tops, and field emergence. Nomo and the newly recommended Monoire show low bolting tendencies when sown early, while Sharp's Klein Monobeet is poor in this respect. Vytomo and Salohill are much less resistant to downy mildew than Monoire or Bush Mono "G".

2.2.5 Commercial seed production

Sugar beet seed is usually grown away from root crops because of downy mildew and virus yellows carry over and possible pollen contamination from bolters (Scott & Longden 1973). Most of the seed used for root crops is triploid hybrid monogerm which is produced by mixing and then sowing together an inbred diploid male sterile monogerm, and a tetraploid multigerm to act as a pollinator. The mixed progeny is mechanically separable into triploid Monogerm and multigerm seed (Johnson 1980, personal communication).

When seed crops are in flower problems such as pollen contamination from weed beet, wild relatives or low fertilisation overall due to unsuitable weather can occur, but the amount of viable seed produced can be low for a number of reasons even if

good fertilisation is achieved (Scott & Longden 1973), (Battle & Whittington 1969a). The maturity of the fruit at harvest can affect seed performance. More mature fruits have better developed embryos and a lower concentration of germination inhibitors (Scott & Longden 1973) and should therefore give better establishment of the root crop.

The actual numbers maturing at harvest depends on the season and the date harvested. Wet seasons delay rate of maturing and often seed is harvested early to reduce losses by windshake. Tekrony & Hardin (1969) looked for the location of under-developed seed on seed plants and found them on all parts but their occurrence was more frequent on tertiary lateral branches. Field removal is therefore not possible and it is also difficult to do so in processing unless there is a relationship between "seed" size and under-developed seeds.

2.2.6 Post harvest treatments

The standard post harvest treatment to raw seed is a complicated and exacting operation but in outline the following is carried out: -

- 1) Pre-cleaned (to remove stick & leaf) and dried to below 15% moisture at a temperature not greater than 120°F (49°C).
- 2) Cleaned with aspiration using round hole screens to remove small and dead seeds.
- 3) Monogerm seed is separated from multigerm seed using a combination of round hole and slotted screens.
- 4) The monogerm seed extracted is graded to size specifications - usually 2.75 - 4.00 mm.
- 5) The graded monogerm seed is gravity separated to extract light "weak" seeds to improve germination.

- 6) The product is soaked in a fungicide solution of organic Ethyl Mercury Phosphate (E.M.P.) for twenty minutes - by using a concentration of 40 ppm. E.M.P. and a ratio weight of three parts water to one part seed.
- 7) The final seed product is then regraded to size specifications (Lindsay 1980, personal communication).
- 8) Pelleted.

2.2.7 Pelleting

Nearly all the seed sown in the U.K. is pelleted as there are several advantages over raw-rubbed seed. The major advantage is more accurate drilling and others are safe dressing with fungicides, protection from mechanical damage and sowing depths and spacings are easily checked (Charlesworth 1978).

There are many materials and methods which can be used for Clays such as Cellite, Montmorillonite, Vermiculite or Bentonite, or other materials such as cork, peat, chalk, sand or even beet cortex can be used. Non-clay materials may need a sticker such as ethyl cellulose to hold the pellet together. Clay structures generally adhere with water only, but they need sufficient physical strength to resist damage in the drill but breakdown easily on contact with soil water.

The three main methods of pelleting are stamping, coating or rolling. Stamping is a dry process and is therefore rapid but any additive must be evenly distributed throughout the pelleting material, while coating and rolling permit layering of additives anywhere within the pellet.

Drying after pelleting is necessary and slows the procedure down (Longden 1975).

The most popular process in the U.K. is the Germain's "Filcoat". About 1600 tonnes of seed are pelleted annually with a secret clay-based medium (Charlesworth 1978), plus methiocarb insecticide @ 4 Kg/1000 Kg seed (Johnson 1980, personal communication). Manganese Oxide can also be incorporated for use in deficient soils (Farley & Draycott 1978).

2.2.8 Alternative seed treatments

Sugar beet seed has to be processed between harvesting and sowing to eliminate inferior seed, and give good seed a better chance of good and fast emergence. The standard procedure listed removes empty and shrivelled seeds and multigerms, and gives protection against some pests. and pathogens but often field performance is far from perfect, therefore better treatments should be sought. The problem in finding suitable alternatives is not that treatments do not improve seed performance when used singly but more often because there are practical difficulties or incompatibility with existing treatments or simply the cost and time involved (Tonkin 1979).

(i) Washing

Longden (1973) showed how 21 rinses in 3.5 hours gave the best response in glasshouse and field trials with natural and partially processed seed; but when agitated, washed seeds showed a greater tendency to lose seed caps and therefore this was an unsuitable treatment. Washing had similar effects on the performance of both mature and immature seed.

(ii) Advancing

The object of advancing is to allow seeds to imbibe water and develop physiologically up to the point of

radicle elongation and then be dried back, holding the seeds at this point before sowing. This reduces the period between sowing and emergence in the field.

The optimum advancing technique for sugar beet was determined by Longden (1971), (equal weights of seed and water in airtight containers for 24h, repeated 3 more times with a 48h air drying interval after each soaking). Advancing increases the number of cells in the true seed but the treatment does not increase the size of individual cells so that the germination process does not therefore result in large changes in embryo volume before the radicle elongates, but like washing, advancing increases the tendency for premature loss of the seed cap. An extremely gentle drill mechanism would therefore be required. Fluid drills may be developed for practical use.

While washing was calculated to be equivalent to a very much higher than normal rainfall over the seed plant, rainfall effects are more similar to advancing than washing, i.e. a small amount of water in contact with the seed for a longer time.

(iii) Osmotic priming

This treatment is also designed to get the seed in a better physiological state for quick emergence. Trials with various concentrations and priming periods in polyethylene glycol or salt ($\text{KNO}_3 + \text{K}_3\text{P0}_4\text{H}_2\text{0}$), (Longden, Johnson, Darby & Salter 1979) gave poor and inconsistent results and no reduction in the

time spread of germination. Priming is therefore too unreliable to use in practice.

(iv) Water steeping

Longden et al (1979) also looked at the effects of a 24h soak in 10 x the seed volume of water @ 1°C followed by re-drying. Steeping gave uniform germination but poor field performance.

Scott, Wood & Harper (1972) however found that a 24h soak in water @ 20°C hastened emergence and improved final germination. The steeping process probably has effects on physiological developments and also removes germination inhibitors.

(v) Plant growth regulators

Scott et al (1972) compared steeping seed in solutions of kinetin (K), 6-benzyl-aminopurine (BA) and gibberellic acid (GA₃) with water only. All solutions gave better field emergence than water but also showed a response to concentration. The optimum concentrations were BA 1 - 10 ppm, K 50 - 100 ppm, GA₃ - 100 ppm which nearly doubled the seedling weights.

(vi) Size grading of seed

Longden, Scott & Wood (1974) devised a size grading method which could produce a seed lot containing 90% monogermers and a germination of 80%, providing the unprocessed raw seed had at least 50% germination. The method included grading by thickness to remove multigerms, and grading by diameter and aspiration to remove small and non-viable seeds. The variation in size range was also reduced in the process. However, an ideal sequence for size grading cannot be

formulated as there is much variation between original seed lots due to effects of season, seed production agronomy and variety. The optimal adjustment and sequence for one seed lot may be totally unsuitable for another.

(viii) Treatment combinations

Any number of treatments can be used on a seed lot but to be of value they should be

- a) fully compatible,
- b) additive in effect or, preferably,
- c) synergistic (Longden 1976).

Longden (1976) tried washing, E.M.P. steeping, Thiram soaking and advancing in sequence on a seed sample of Amono graded 3.18 - 3.57 mm. One or more of the treatments were omitted on other Amono samples so that a total of 16 different combinations of treatments were obtained for comparison. When analysed, different aspects of seed performance were affected and complex interactions occurred - some combinations gave faster emergence, others larger shoots. In general, as more treatments were applied detrimental effects were observed, e.g. E.M.P. had positive effects on seed performance when used singly, but negative in combination, (when additional soaking let Hg penetrate the embryo). It was probable that there was considerable overlap in the effects of single treatments and there was no evidence of cumulative or synergistic benefits from combinations. Therefore only one treatment involving water or a solution should be used on a seed lot and in practice this is the E.M.P. steep to control seed borne fungi.

2.3 Factors affecting germination

2.3.1 Introduction

This section is mainly concerned with laboratory seed testing as affected by storage, natural inhibitors and various treatments. The most important factors in a petri-dish test are the access of oxygen to the true seed and of water which is discussed in some detail. The importance and limitations of germination tests are considered.

2.3.2 Seed storage

Sugar beet storage is not a problem in the U.K. The cool ambient conditions allow commercial seed to remain usable for several years. Longden & Johnson (1974b) studied the effects of storage temperature and water content with time on seed performance with pelleted and unpelleted Amono and Monobeet. Both higher water content and temperature lead to quicker loss of viability over the range 5 - 18% H₂O and 2 - 22°C; in the extreme case of storage under conditions of 18% and 22°C, seeds were completely dead after 13 months storage. Seed stored in open containers @ 10°C produced about 9% fewer seedlings per annum relative to the initial value (= 100) over five years, while both pelleted and unpelleted stored in sealed thick polythene bags showed almost no decline with a water content of 5 - 10%.

Sometimes an increase in germination over the first year of storage was observed. This was most probably due to a combination of saprophytic fungi on the seed surface dying and loss of post harvest dormancy. Storing at lower temperature (2°C) gave seedlings of lower dry weight when tested. Storage of beet seed at about 10°C is considered appropriate and this temperature is relatively cheap and easy to maintain.

In warm humid climates seed viability does decline and methods of minimising losses are required. Basu & Dhar (1979) found that soaking in 5 x the volume of water followed by re-drying before storage reduced the loss of viability over three months of storage. No chemical solution had a better effect than water but the exact mode of action of the hydration/dehydration process is not known. There may be an effect on inhibitors in the seed or on free radicals.

Another problem is that seed vigour deterioration occurs before loss of viability can be determined by standard germination tests. Seed vigour is a measurement of the ability of seeds to germinate or emerge under non-optimal conditions. Low vigour is associated with slow emergence which is extremely undesirable for high sugar yield.

2.3.3 Germination tests

The requirements for a standard germination test for many species including Beta vulgaris are defined by the International Seed Testing Association (Anon 1966). The conditions for sugar beet are 16 hours @ 20°C, and 8 hours at 20 - 30°C per day with germination counts at 3 and 14 days. Light is not essential and the test can be carried out on top of or between filter paper, or in sand. The seed should be pre-washed for 1 hour in water at 25°C.

The object of the standard test is to gain information about the field planting value of the seed under test and to compare it with other seed lots. The defined conditions are designed to allow the seed lot to express regular, rapid, and complete germination, and also be repeatable within the limits of the random sampling. However, sugar beet field emergence is not accurately predicted by the standard test (Brown 1980).

Hibbert and Woodwark (1969) have tried other laboratory tests using pleated paper or flat paper in sealed containers at different temperatures and periods of counting. Results were similar but not interchangeable and the inherent variability of seedlots makes emergence prediction a procedure with low precision. Sand is considered to be an unsuitable medium for germination tests but Snyder and Filban (1970) in the U.S.A. praised a test for emergence potential of seed from a standardised sand tray.

Hibbert, Thomson and Woodwark (1975) and Reiff (1976) cited by Johnson (1979) found that pleated paper gave good laboratory germination, as the contact between seed and paper was better than with flat filter paper. Brown (1980) found low temperature results more accurate for field emergence prediction, but this procedure is lengthy. Bonscheur (1975) cited by Johnston (1979) found that the speed of germination but not the final value was affected by varying temperatures and water contents, but Heydecker, Orphanous and Chetram (1969) recommended that care should be taken not to penalise seed by either excess or a lack of water when under test (using garden varieties of red beet).

2.3.4 Effects of inhibitors on germination

Many substances have been isolated from the seed coats of sugar beet which are potentially inhibitory to germination, most of them are organic acids. Snyder, Sebeson & Fairley (1965) considered Oxalate to be the major inhibitor but did note some complex interactions with others. It was concluded that effects were specifically inhibitory rather than osmotic. Sebeson, Mitchell & Snyder (1969) studied the effects of inhibitors on Alpha-amylase activity on starch solutions (hydrolysis of starch is an essential process before germination commences). The

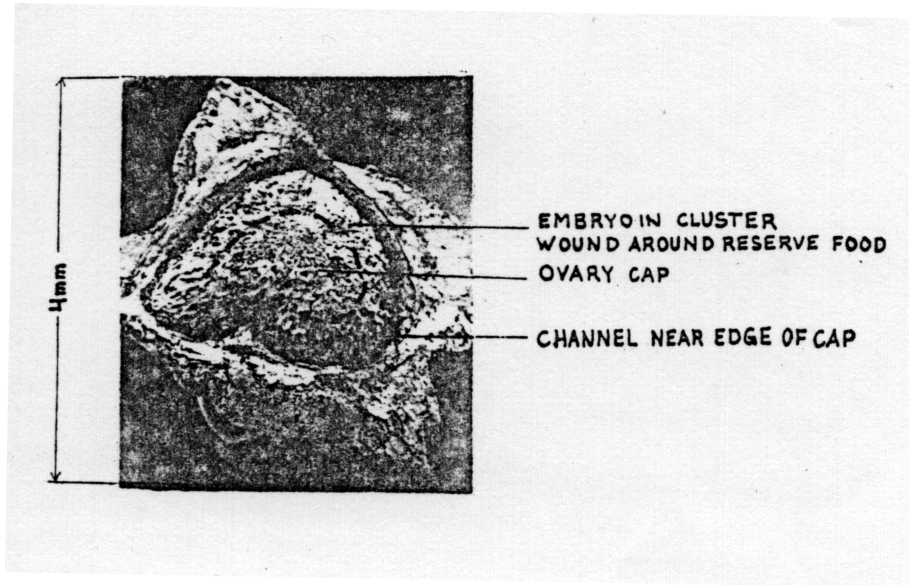
inhibitory effects of Caffeic, Ferulic, Gallic, P-hydroxy, Benzoic and Vanillic acids, which are known to exist in beet seeds, were examined using Alpha-amylase and excised embryos. Gallic acid was found to be most inhibitory and, in general, the degree of inhibition increased with concentration in both experiments, but the effects were less pronounced on the embryos, indicating that some form of detoxification must occur in the seed. Battle & Whittington (1971) showed that the maternal genotype influenced the early field behaviour of the progeny through control of the level of inhibitors in the seed. In earlier experiments, Battle & Whittington (1969b) showed that the inhibitors were situated in the perianth and pericarp, and also that the various other acids, including Abscisic, were involved. It was postulated that the free phenolic acids were in equilibrium with acetone insoluble esters involved in lignin bio-synthesis. Immature clusters would have a relatively higher proportion of P-coumaric acid associated with an earlier stage in lignin biosynthetic pathway.

Inhibitors may also act as O_2 acceptors and affect germination in this way (Heydecker, Chetram & Heydecker 1971).

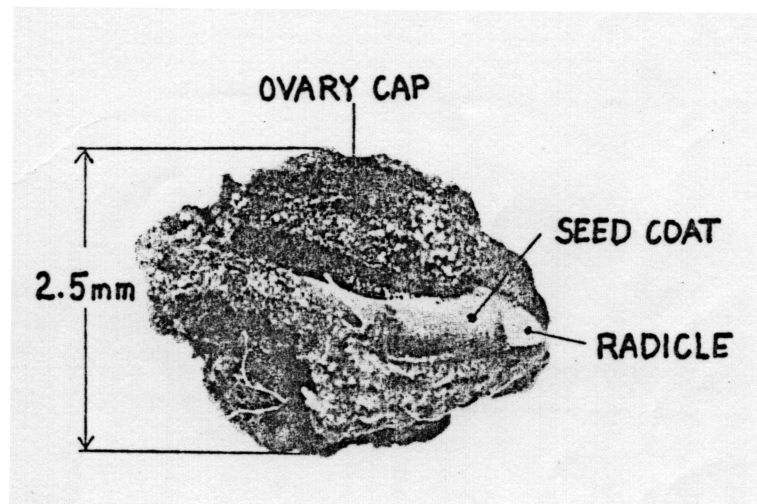
2.3.5 The germination process and the involvement of air and water

Water and oxygen must be taken up before germination can occur. The figures on Pages 16 and 17 show that the embryo is concealed inside the seed coat which acts as a barrier to both, but the basal pore does permit entry. The pore is not usually open, but contains the remains of the vascular connections between the mother plant and the embryo.

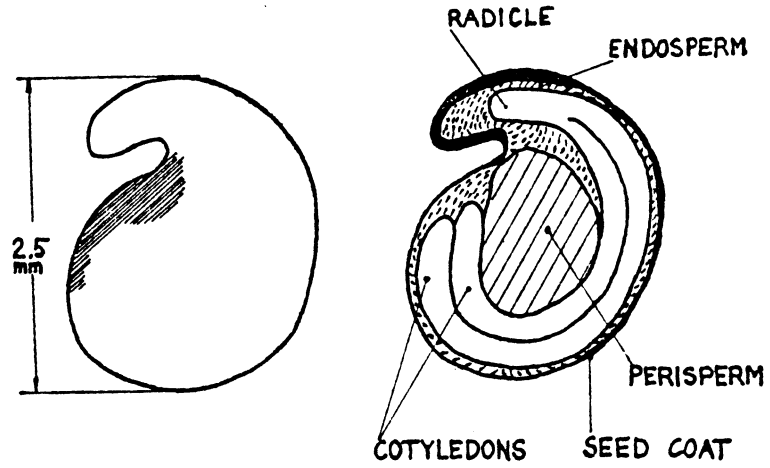
Perry and Harrison (1974) almost completely prevented germination by blocking the pore with Vaseline. Entry between seed cap and the seed coat does not occur as Heydecker et al (1969) had earlier described.



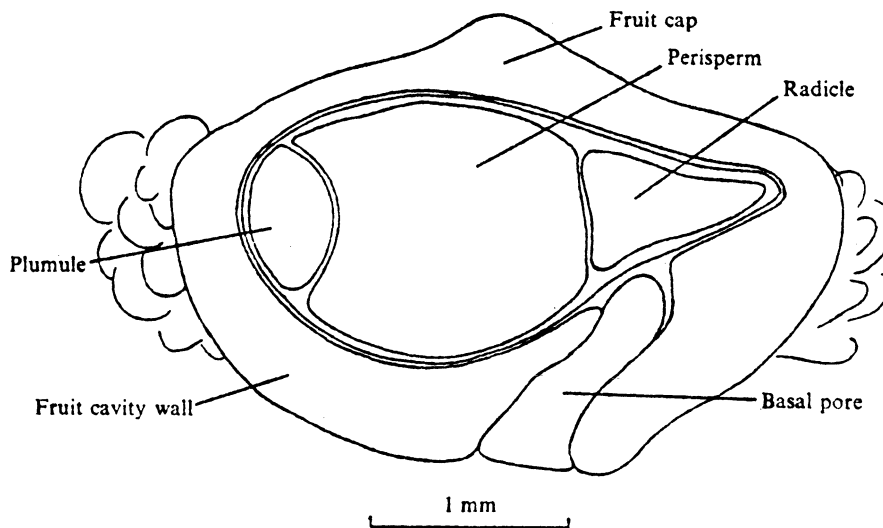
(i) Monogerm seed of variety Monohill (Aura 1975).



(ii) Opening of the seed cap and radicle emergence after two days (Aura 1975).



- (iii) Diagrams showing external view and out-section of a true seed (Lakon & Bulat 1958 cited by Aura 1975).



- (iv) Diagram of a transverse section of a monogerm seed (Perry & Harrison 1974).

Severe inhibition has also been described in many papers including Chetram & Heydecker (1967) and Heydecker & Chetram (1971) by excess water in the test substrate. Excess water tends to be taken up and held in the basal pore by capillary action. Consequently, oxygen can only enter by diffusion, through the water at a very slow rate.

Perry and Harrison (1974) applied Fick's Law to the dimensions of the basal pore and estimated that, when air filled, the oxygen diffusion flux was 4.5 ml/h and when water filled only 8.5×10^{-3} $\mu\text{l/h}$. An embryo requires about 0.8 $\mu\text{l/h}$ to germinate and therefore the process is inhibited when the pore is full.

The observed uptake of oxygen in a water filled pore was 0.14 $\mu\text{l/h}$. The difference from the water filled pore estimate was due to microbial respiration.

As germination continues cell number increases (Longden 1971) then the radical elongates forcing the seed cap open thus making more oxygen available to the embryo facilitating faster elongation. Coumans, Côme & Gaspar (1976) showed that in a wet medium removing the cap before germination resulted in more seed germinating if positioned "face up" but not if "face down". Therefore the external film of water could also inhibit germination. Peto (1964) cited by Heydecker and Chetram (1971) chipped the seed cap beforehand and improved germination by both allowing more oxygen in and reducing the mechanical effort required by the radical to remove the cap. Heydecker and Chetram (1971) viewed germination as more than a physiological process, i.e. complex ecological and microbiological components are involved too. When 8 ml of water was used in a laboratory test dish it was excessive, but adding aureomycin to inhibit bacteria leaves more oxygen for embryos to use. Washing seeds upsets the ecological balance between bacteria, fungi and the inhibitors in the seed coat, and

the depressed laboratory germination of seeds treated with fungicides may be explained by a similar change to the micro-environment.

As germination is improved by cap removal or inhibitor removal, whether water is excessive or not, O₂ uptake and respiration must therefore precede germination and not be a consequence of it! However, Heydecker et al (1971) noticed that in red beet seeds when the concentration of inhibitors was high, the oxygen uptake was high also. Therefore, some process different from normal respiration was occurring. There may be competition for oxygen between different metabolic pathways with imbibed seeds - inhibiting respiration at low concentrations and uncoupling, i.e. preventing access to the true seed, if at higher concentrations but an actual mechanism has not been found.

Coumans et al (1976) viewed the seed coat as a physiochemical barrier to oxygen. It (a) restricted diffusion and (b) actually absorbed oxygen so that very little if any reached the embryo through the seed coat.

Chetram & Heydecker (1967) and Heydecker et al (1969) found that hydrogen peroxide in solution was an excellent way of supplying oxygen to the embryo to improve germination.

2.4 Factors affecting the establishment of beet

2.4.1 Introduction

Regular sugar beet stands used to be achieved by sowing seed at a high rate and subsequently hand hoeing unwanted plants after emergence. However, now that monogerm seed, precision drills and suitable herbicides have been introduced, regular stands can be achieved without handwork. Nevertheless, modern methods of establishment are not always completely successful as Bray (1980)

has shown. Nearly half the area "drilled to a stand" receives at least a small amount of handwork.

The main reason for this is that sugar beet field emergence is difficult to predict even when laboratory germination is known. This section discusses the factors affecting emergence but firstly optimum or target populations are considered.

2.4.2 Plant population

Hull and Jaggard (1971) reviewed attempts to determine the population for maximum yield of sugar and found many factors, viz. soil type, irrigation, sowing technique and fertilizers, affected this optimum population. They generally concluded that this was 65,000 plants/ha on a fertile soil rising to 85,000 on poorer soils, but a few thousand above or below did not seriously depress yield. Goodman (1966) recommended 74,100/ha with a leaf area index (L.A.I.) of 2.8 (which does not intercept all available radiation but ensures there are no non-productive leaves). The above recommendations were based on hand-hoed situations only where a dense crop was sown and subsequently thinned. Draycott & Durrant (1974) looked at populations in relation to other cultural practices, and showed 50,000 or above was adequate without hand-hoeing. It was also shown that between a rectangularity of 1:2 and 1:1 yield was not affected at higher populations (86,000/ha) but Hull & Jaggard (1971) showed that 45 cm rows were more suitable for high populations and 60 cm for lower populations to reduce interplant competition in both cases. Interplant competition was shown to reduce individual plant yields considerably by Draycott & Durrant (1974) who compared sugar yields from plants grown in a competition free plot (22,000/ha with minimal nutrient and light competition and adequate soil water) with denser stands.

At 22,000/ha individual plants yielded 315 g of sugar/plant but at 81,000/ha individuals yielded only 113 g, but a much higher total yield/ha.

2.4.3 Cultivation and seed bed preparations

Cultivation for sugar beet should make the best use of the available environmental conditions over the preceding Autumn and Winter. The following practices should ensure a reasonable quality seed bed in the Spring.

- 1) Plough early with a reversible plough to gain the benefits of an even surface for an even depth of weathering, and as long a weathering period as possible.
- 2) Use as few passes as necessary with wide wheel extensions, to minimise excessive consolidation. Use wide implements and tandem arrangements.
- 3) After weathering use shallow cultivations only to avoid bringing clodding unweathered material up into the seed bed.
- 4) Form a coarse tilth below the surface for drainage but a finer tilth on the surface for water conservation.
- 5) A level seed-bed should be achieved by use of straight and rolling tined harrows or power harrows, so that precision drills can be used and drilling depth controlled (Spoor 1978, Clare 1976 and Rose 1972).

2.4.4 (i) Drilling

Precision drills are now almost universal in use and are essential for the "drilling to a stand" technique. A precision

drill is defined as one which selects and deposits seed at predetermined distances. Common features of precision drills are: land wheel drive, minimum seed drop, boat shaped coulter and flat rollers (Rose 1972). In the U.K. the "Stanhay" pinched rubber belt drill is used, but disc types are popular elsewhere (Hull & Jaggard 1971). Ten or twelve row machines are necessary to compensate for slow forward speed of precision drills, but the N.I.A.E. have a test drill accurate at 11 km/hr (Hayward 1978). Munday (1977) has shown that no commercial drill sows perfectly. Doubles, singles or multiple misses and inconsistent spacings are always observed, but the seed can confound the drill performance when doubles are due to pellets with extra embryos and misses due to dead or empty ones. However, better drills that reduce the amount of seed roll and that are more accurately space-calibrated are required for "drilling to a stand".

Beet seeds should not be sown below 3.8 cm due to the small perispermic reserves. Early sowing should be shallow (< 2 cm) for good emergence. If sown later then 3 cm is better as the surface dries out (Hull & Jaggard 1971, Hibbert et al 1975).

Alternative drilling techniques such as fluid drilling of pre-chitted seed (Longden et al 1979, Currah 1978) have as yet unsolved technical problems and cannot be used for fast and even emergence in sugar beet.

(ii) "Drilling to a stand"

"Drilling to a stand" is only successful with precision drills, good emergence and relatively weed free fields. In the U.K. 12 - 15 cm spacing in 50 cm rows is commonly used to achieve 74,000/ha but Fletcher (1974) has shown that no universally recommended spacing is possible as localised factors are involved. The technique works best for April sowing when compensatory growth

is adequate to make up for irregular spacing. Neeb and Winner (1970) cited by Hull and Jaggard (1971) deliberately mixed good and dead seed to encourage irregular spacing and reduce population and still found a linear relation between population and yield up to 80,000/ha. However, Thomson (1956) cited by Hull and Jaggard (1971) also deliberately obtained an irregular stand by random hand-singling and found 0.5 t/ha less from an irregular stand than from a similar regular, hand-singled stand. Knott, Parker & Mundy (1976) found that with "drilling to a stand" irregularity effects were worse with low populations, made with wide rows and spacing, and at the same time found 70,000/ha was optimal for a fen soil, but only 50-56,000 for a silt.

2.4.5 Field emergence

Aura (1975) categorised four factors involved in emergence:

- 1) The germination energy of the seed.
 - 2) The appearance of pathogens.
 - 3) Mechanical soil resistance.
 - 4) Soil, air & water content.
-
- (i) Germination Energy. Perry (1973) showed monogerm final emergence to be reduced by high soil water levels and by compaction, but not by low soil temperature. However, seed lots responded differently showing that seedling vigour is important.
 - (ii) Effect of fungicide. Heydecker & Chetram (1971) showed that seed fungicide treatment improved field performance even if laboratory tests showed the reverse.

- (iii) Hegarty and Royle (1978) measured the impedance of soils covering sugar beet seeds and showed a negative linear correlation with final emergences. Perry (1973) also showed how soil capping caused by irrigation water reduced emergence by 30%.
- (iv) Aura (1975) considered oxygen uptake was only seriously hindered by water in the seed or the surrounding film, when soil water potentials were close to zero, i.e. in very wet soils. Poor contact between soil and seed could reduce germination by restricting water uptake in dry soils, if the soil water potential and was less than - 10 atm no emergence occurred. Aura also noted water diffusion to be slower through the seed than through the soil. Pelleted seed emerges better in wet soil conditions (Perry 1973), and Hibbert et al (1975) postulated that pelleted seed may have a higher water requirement and should be sown slightly deeper in dry conditions. Aura (1975), however found pellets restricted oxygen uptake in very wet conditions.

2.4.6 Predicting sugar beet emergence

The standard germination test is fair to the seed in that individual seeds have minimal stress and therefore if germination is possible it should occur. However, sugar beet growers require information on field emergence potential and therefore tests with inbuilt stresses may be more appropriate. Perry (1973) has shown how field stresses affect beet seed lots differentially and prior knowledge of this would be very useful for seed selection for a particular situation.

Brown (1980) suggested low temperature tests (5-7°C) as viable seeds which germinate at 20°C may not do so at lower temperatures which would be experienced in the field. Longden, Johnson & Love (1970) developed a radiography test for laboratory emergence and Longden and Johnson (1974a) compared a radiography test with other methods, i.e. leachate conductivity, a pleated paper test (Hibbert & Woodward 1969), and growing in compost, for prediction of field emergence.

The radiograph prediction is based on x-ray photographs of seed, assessed visually into "good", "dead" and "uncertain" categories. Filled cavities, shrivelled seed, empties and double embryos can be identified with this method. However, not all seed classified as good will germinate, and therefore radiography tends to over-estimate laboratory germinations. Germination in compost was predicted equally well with radiography and standard germination tests. For field performance the leachate conductivity method was hopelessly inaccurate with pelleted seed and poor with unpelleted seed and was therefore discarded as a prediction method. The compost test was more accurate but took three weeks and was roughly equivalent to a radiography prediction. However, radiography does not work for pellets. Overall the pleated paper and the standard test gave the best prediction. It was noted that a low laboratory germination always resulted in poor field performance, but a high laboratory value could result in a high or low field result.

The method of prediction of field performance was a linear regression, e.g. $Y = 0.64 X + 6.2$ where Y is field emergence (%) and X is laboratory germination (%) but using a field factor is simpler. A field factor of 72% would mean a grower could expect 72% of the laboratory germination to emerge in the field.

The field factor can be applied to this formula (Bleasdale 1963 cited by Longden & Johnson 1974a).

$$N = \frac{P \times 100}{G \times F}$$

Where:-

- N = no. seeds required/ha
- P = desired population, plants/ha
- G = laboratory germination %
- F = field factor.

However, as sugar beet establishment is variable, estimating the field factor may not always be accurate enough for practical use of the formula, but it shows that improving the field factor by preparing better seed beds will reduce the number of seeds required to produce a regular stand.

2.4.7 The effect of seed size on emergence

Snyder & Filban (1970) compared fruits graded 2.58 - 2.98 mm and 3.77 - 4.12 mm in diameter sown at different depths, 3.2 cm and 5.1 cm in sand. The deeper and smaller seed reduced establishment. The hypocotyls of the deeper sown seeds were heavier as increased impedance forced them to widen.

In the field, emergence was as shown:-

Seed size (mm)	Depth of sowing	
	3.2 cm	5.1 cm
2.58 - 2.98	37%	20.5%
3.77 - 4.12	51%	38%

Snyder and Filban (1970) recommended seed rates should be increased by 33 per cent when using small seed, and that small seed should always be sown at less than 2.5 cm. When soil

moisture is limiting, deep sowing of large seed should be used. Lindsay (1980 personal communication) showed that seed less than 2.75 mm is eliminated in processing and so only large seed is used in practice. mm) and Large (5.2- 5.6 mm) seed were used.

Overall the embryo weight was about 20% of the "seed" and larger seeds had fewer empty cavities. They confirmed that the large seed within a seed lot gave a higher percentage emergence and was more reliable.

After processing, larger seed still performed better.

Plants produced from larger seed had higher root: shoot ratios but at harvest plants from medium and large seed produced similar yields. Possibly selecting for seed size also selected different genotypes.

2.4.8 Other emergence factors

(i) Fertilizers

Providing the recommended rates are used (100 Kg/ha N, 100 Kg/ha P₂O₅ & 200 Kg/ha K₂O MAFF 1979), fertilizers do not have a large effect on establishment except for nitrogen which can be used to encourage early leaf growth. Nitrogen should be applied in the Spring at least two weeks before sowing to allow high localised concentrations to be diluted by rainfall before scorch damage of seedlings occurs (Last & Draycott 1979). The other nutrients, and, if required, Na and Mg, can be applied in the Autumn (Draycott 1977).

(ii) Fungicides

Byford (1977) studied the effects of mercury fungicides on emergence. Maneb, Captafol and 2-(Thiocyanome-thylthio) benzothiazole (T.C.M.T.B.) seed treatments were compared with the standard E.M.P. treatment. No treatment was as good as E.M.P. and only maneab was similar. It has been estimated that national emergence would be 10% lower if E.M.P. was replaced by another fungicide. Other environmental factors had much larger effects on emergence overall, but E.M.P. treatment is definitely justified as the untreated control had a 20% lower emergence.

(iii) Pests

Pest control measures in addition to seed dressing are sometimes required for pests which effect establishment. Millipedes and beetles can be troublesome but Gamma HCH worked into the seed bed before sowing gives control. Wood mice which dig up seeds and seedlings can be controlled by traps or poisoned food if numbers are high after a mild winter (Farmers' Weekly 1979).

(iv) Weeds

Weeds are no longer a major problem to establishment as good herbicide control is now possible with soil acting herbicides such as chloridazon or ethofumesate (Bray 1980).

(v) Cold injury

Cary (1975) showed that seedlings on the point of emergence were more sensitive to frost damage than at any stage before or after, and that no chemical used to promote winter hardiness in other species

affected sugar beet similarly. However, germination at low temperature and osmotic treatments did reduce sensitivity to frost damage.

(vi) Soil temperatures

The effects of soil temperature are more important than the actual sowing date as Scott et al (1973) have shown. The date that the amount of accumulated day degrees over 5°C begins to increase rapidly is a good indicator of the onset of growing weather. However, this can occur at any time between 1st March and 20th May, but most commonly between the 1st and 10th of April. It is usually best to sow just before the onset of growing weather.

2.5 Alternative methods of establishing beet

2.5.1 Transplanting

Scott & Bremner (1966) investigated the potential of transplanting with multigerm varieties as an alternative to contemporary practises and found that an extra ten tonnes/ha of roots and more tops could be obtained. The technique resulted in more fangy and globular roots developing, but the desired plant populations were easily obtained. The larger leaf area duration of the transplants made them more drought sensitive, but in the experiment drought did not seriously check yield. High populations were not required as it was realised that it was the period of ground cover and not the L.A.I. obtained that had the main effect on yield.

In 1966 it was postulated that commercial success would be possible if suitable mechanisation at an acceptable cost could be developed but it was not forthcoming in the U.K. However, in Japan and Bavaria transplanting is used.

More recently ADAS have started to re-investigate the technique and preliminary trials with monogerm varieties in paper mini-pots show promise of a 40% yield improvement (Farmers' Weekly 1980).

Some other advantages have been noted, namely a reduced dirt tare and better root shape which contrasts with Scott & Bremmer, but handling costs are still prohibitive.

2.5.2 Autumn sowing

Wood & Scott (1975) showed that October and September sowing gave full leaf cover by mid-June, thus making more efficient use of radiation, up to 40% of the available between April and June. Thereafter bolting occurred and final sugar yields were never better than Spring sown crops, even if hand rogued. Ethephon applied at 10 g/1 partly controlled bolting but killed 55% of the plants. At a lower dose (2 g/1) it was ineffective.

It was concluded that Autumn sowing was unsuitable for the U.K. unless extremely bolting resistant varieties could be developed. This is unlikely as flowers are needed for breeding.

Autumn sowing is also inadvisable as virus yellows and downy mildew would be carried over more easily. Autumn sowing is practised in warmer climates, viz. Italy and Japan where low temperature induced bolting is not a problem.

2.5.3 Conclusion

In this review, sugar beet establishment has been shown to be the "weak link" in the production of high sugar yields. The various alternatives for all stages from seed production to establishment all have too many drawbacks to use in practice. The following experimental section is principally concerned with methods of testing and improving the laboratory performance of beet seed, which may result in better field establishment and higher yields.

3. EXPERIMENTS

3.1 Materials and Methods

3.1.1 Description of Seed Lots

The general objective of the experimental work was to compare the germination performance of five different lots of sugar beet seed under several different test conditions with various treatments, and relate the performance to features of the seed lots. The five seed lots used were as follows:-

Lot 1, variety Monotri, harvested in 1977;

Lot 2, variety Monotri, harvested in 1975;

Lot 3, Bush Mono "G", harvested in 1979;

Lot 4, Amono, harvested in 1979;

and Lot 5, Nomo, harvested in 1975.

Lots 1 2 and 5 had been lightly rubbed after harvesting but not further treated, while Lots 3 and 4 had received the complete commercial processing and pelleting procedure as described in Sections 2.2.6 and 2.2.7.

3.1.2 Seed Characteristics

One hundred air-dried seeds from each lot were weighed, (before and after de-pelleting by washing in running tap water where necessary). The true seeds were dissected out from all seeds by lifting the seed cap with a dissecting needle, after soaking in water for 12 hours, and then weighed individually. The relationships between total and true seed weights were determined. Moisture contents of each seed lot were also determined using an infra-red moisture meter and milled seed samples.

3.1.3 Germination and Emergence Tests

The purpose of Experiment 1 was to test all five seedlots under conditions similar to those defined by the International Seed Testing Association (ANON 1966), as described in Section 2.3.3.

Germination counts were taken at intervals to determine the final germination percentages, and mean germination time (M.G.T.).

The procedure used for this test was as follows:-

1. Four groups of fifty seeds were counted out from each of the rubbed seed lots. Small, damaged and multigerm seeds were excluded as it was assumed further processing would also have removed them.
2. Four groups of fifty pelleted seeds were counted out from the commercial seed lots (without selection). The pelleting material was removed by washing.
3. All seeds were soaked in tap water for approximately 1½ hours.
4. After a short period of air drying, each lot was placed in a 9 cm petri-dish containing three Whatmans' grade 181 filter papers and 5 ml of distilled water. The dishes were covered and placed in a temperature controlled incubator without illumination. The temperature was maintained at 20°C for 16 hours and 25°C for 8 hours per day (standard temperatures).
5. In this test germination counts were made initially at 2 day intervals, but the counting interval increased as germination approached completion.
6. Seeds were counted as having germinated when the radicle had forced the seed cap open and could be seen emerging from it.

7. As some of the selected seeds contained more than one true seed, despite the attempt to exclude them, they were considered to have germinated if one or more radicles appeared.

This procedure was chosen after considering the observations of Chetram and Heydecker (1967), Perry and Harrison (1974), and Hibbert and Woodwark (1969). Five ml of distilled water on three filter papers was known not to be excessive for germination. Experiment 1 was repeated at the end of the experimental period, (October 1980 - February 1981) to test for changes in germination performance in any of the seed lots.

The aim of Experiment 2 was to test seed germination at a lower temperature than the standard recommendation. It was suggested by Brown (1980) that spring-sown seed experiences seed bed temperatures well below those recommended for the standard test (ANON 1966). The procedure used was the same as in Experiment 1 except that the incubator was maintained at a constant 7.5 C, and also seed lots 2 & 5 were started two days before the others. This was because it was anticipated that these lots would take longer to reach the period when most seeds germinate. The temperature was selected to be low enough to allow germination, but not so low as to considerably prolong the duration of the experiment (Brown 1980).

The petri-dishes used in Experiment 2 which still contained ungerminated seeds after 30 or 32 days for Lots 1, 3 & 4, and 2 & 5 respectively were transferred to a cabinet at standard temperatures as germination at 7.5°C was considered to have been complete.

Germination counts were taken to assess the proportion of seeds which would germinate under standard conditions but not at 7.5°C. After a further 19 days germination at standard temperatures was considered complete.

The remaining ungerminated seeds were dissected to determine qualitatively if the true seeds were shrivelled or absent, or apparently normal.

Experiment 3 was a repeat of both Experiments 1 and 2 with advanced seed. The aim was to test the effect of advancing as a seed treatment, on germination performance at both standard and low temperatures. The advancing procedure used was as follows (Longden 1971):-

1. Samples from the pelleted seed lots were washed to remove the pelleting material.
2. Approximately 1000 seeds from each of the rubbed seed lots were weighed and placed in a 9 cm petri-dish.
3. Stage 2 was repeated with the de-pelleted seeds.
4. Tap water was added to each dish in an amount approximately equal to the weight of each seed sample in each dish.
5. The dishes were covered for 24 hours at room temperature, then uncovered with the contents spread out to dry for a further 48 hours.
6. Stage 5 was repeated twice, so that each seed sample received a total of three advancing cycles.

The seeds were then counted and set up as for Experiments 1 & 2, except that the 1½ hour pre-soak was omitted. The test at standard temperature was named Experiment 3 (i), and the low temperature test Experiment 3 (ii). It was noticed that during the advancing procedure some seeds germinated, and seed caps became detached from others, particularly in the de-pelleted samples. This was also observed by Longden (1971, 1973). However, only seeds entirely intact after the advancing treatment were selected for testing, and in Experiment 3 (i) seed Lots 3 & 4

were not used as there were too few intact seed left in the advanced seed stocks.

The aim of Experiment 4 was to test germination performance with a solution of Gibberellic acid (GA₃) in place of distilled water. The procedure used was therefore the same as in Experiment 1 except that 5 ml of a 100 ppm solution of GA₃ was placed in the petri-dishes, and germination counts were initially made at daily intervals. The concentration used had earlier been found to be optimal for improving germination performance if used in a 24 hour steep before testing (Scott *et al* 1972).

Experiment 5 was a repeat of Experiment 3 (i) (advancing and testing at standard temperature) except that, the tap water used for advancing was replaced by a 100 ppm GA₃ solution. The aim of this experiment was to test the effects of advancing with GA₃ on germination performance. As Experiment 5 was also effectively a treatment combination test, either additive effects or interactions may be observed.

The final test (Experiment 6) was an emergence test. Four replicates of 100 seeds or pellets from each seed lot were sown 2 cm deep in trays containing John Innes number 3 compost. The trays were placed in an illuminated (16 hour photo-period) glass house at approximately 16°C. The aim of this experiment was to examine the relationship between germination and emergence from compost, of the seed lots.

After 16 days seedlings were counted and cut off at soil level. The dry weights of the cut seedlings were assessed after oven drying for 24 hours at 90°C. A final count was made 27 days after sowing for slower emerging seedlings but no dry weights were recorded.

3.1.4 The effect of water-soluble seed extracts on cress seed germination

1. 30 g of seeds from Lots 1, 2 & 5 were pulverised in a hand mill.
2. The milled sample obtained was mixed with 80 ml of distilled water, periodically shaken and left in sealed bottles for 2 days.
3. Five ml of liquid extract was pipetted into petri-dishes containing 3 Whatmans' grade 181 filter papers and 50 cress (Lepidium sativum) seeds. The dishes were incubated as in Experiment 1 with daily counts.
4. Stage 3 was repeated with the extract diluted to 0.5, 0.25, 0.1 and 0.01 of the original concentration. Cress seeds were counted as having germinated when radicles >1 mm were observed. The final germination percentages and M.G.T. of the cress seeds were determined. Lots 3 & 4 were not used for this determination as chemical treatments in the processing procedure may have interfered with cress germination.

3.2 Results

3.2.1 Seed Characteristics

The mean values for various seed characteristics are presented in Table 1. A large proportion of the pelleted seed lots was in the form of the clay pelleting material, but after de-pelleting the mean seed weights of the pelleted seed lots (Lots 3 & 4) were similar to the mean weights of Lots 1 & 5. However, the mean seed weight of Lot 2 was lower than the others.

TABLE 1: SEED CHARACTERISTICS

SEED CHARACTERISTICS	SEED LOT				
	1	2	3	4	5
Mean Pelleted weight (mg)	-	-	69.4	69.1	-
Mean seed weight (mg)	10.39	8.67	11.24	11.57	11.29
Standard Deviation	±1.62	±2.10	±2.11	±2.41	±1.37
Co-efficient of variation	±15.6	±24.2	±18.8	±20.8	±13.2
Proportion of pellet as seed (%)	-	-	16	17	-
Moisture content of seed (%)	10.4	10.2	9.4	9.2	9.8
Mean true seed weight (mg)	3.73	2.92	4.66	3.8	3.46
Standard Deviation	±1.3	±1.13	±1.10	±1.14	±0.87
Co-efficient of variation	±34.9	±38.7	±23.3	±30.1	±24.9
Mean proportion of seed as true seed	36.5	33.6	41.9	32.3	30.1
Standard Deviation	±13.45	±11.65	±8.13	±9.08	±7.49

The mean true seed weights of Lots 1, 4 & 5 were similar, while Lots 2 and 3 were lower and higher than the other lots. The mean proportion of the total seed weight as true seed weight was similar for all the seed lots except Lot 3 which had a greater proportion than the others. The moisture contents of the five seed lots were also similar.

The relationships between seeds and true seed weights are presented in Figures 1-5. Integers plotted on the figures indicate the number of seeds with the same seed and true seed weights.

The relationships revealed highly significant correlations ($P = 0.001$) with Lots 2, 3 & 4, a good correlation with Lot 5 ($P = 0.01$) but a non-significant correlation with Lot 1.

The slopes of the regressions are slightly greater than 1 for Lots 2, 3 & 4 but much less than 1 for Lots 1 & 5. There would appear to be an association between the correlation coefficient and the slopes of the regressions. However when the actual true seed weights and mean proportions of the seed weight as true seed weight are compared Lots 1 and 5 have the largest and smallest standard deviations in both cases (Table 1).

The coefficients of variation for the true seed weights of all 5 lots are all larger than the respective coefficients for the total seed weights indicating that there is relatively more variation in the true seed weights.

3.2.2 The Germination Experiments

The germination patterns for the six germination experiments are presented in Figures 6-11.

The final germination percentages and mean

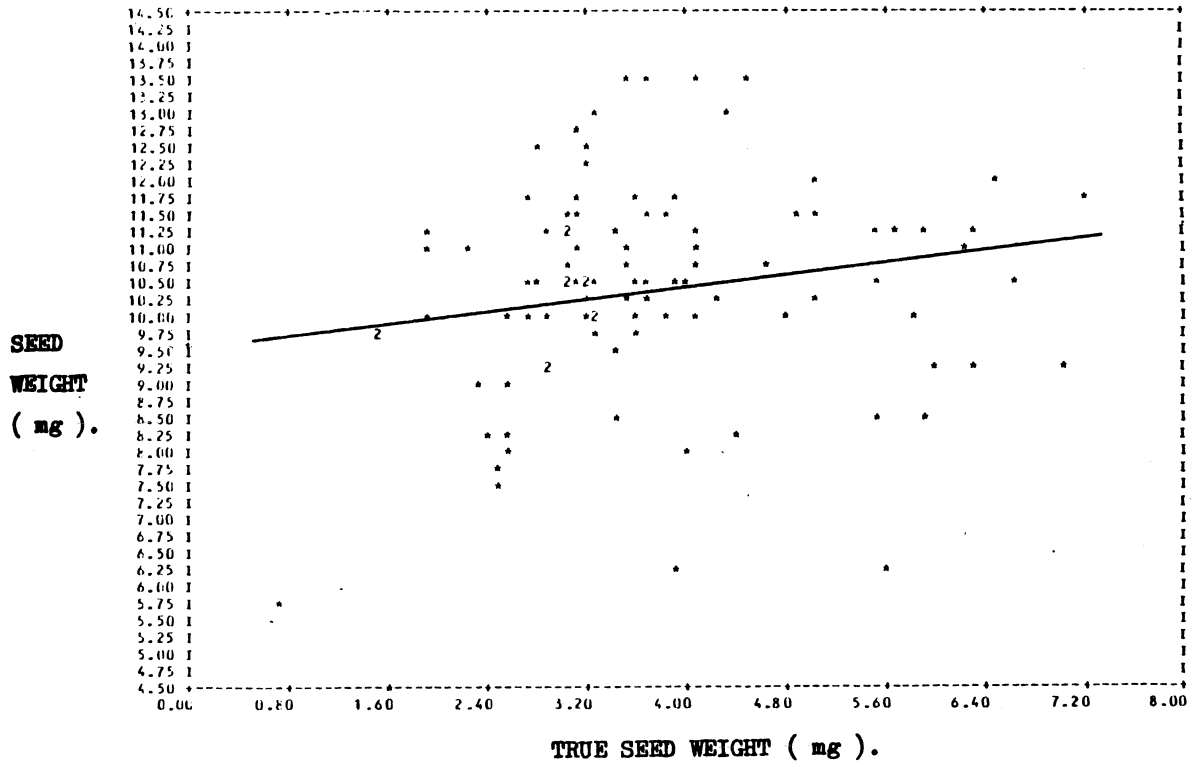


FIGURE 1: THE RELATIONSHIP BETWEEN SEED WEIGHT AND TRUE SEED WEIGHT FOR SEEDLOT 1. LINEAR REGRESSION: $Y = 0.218 X + 9.58$ WHERE Y IS SEED WEIGHT AND X IS TRUE SEED WEIGHT. CORRELATION: 0.1756 (NOT SIGNIFICANT)

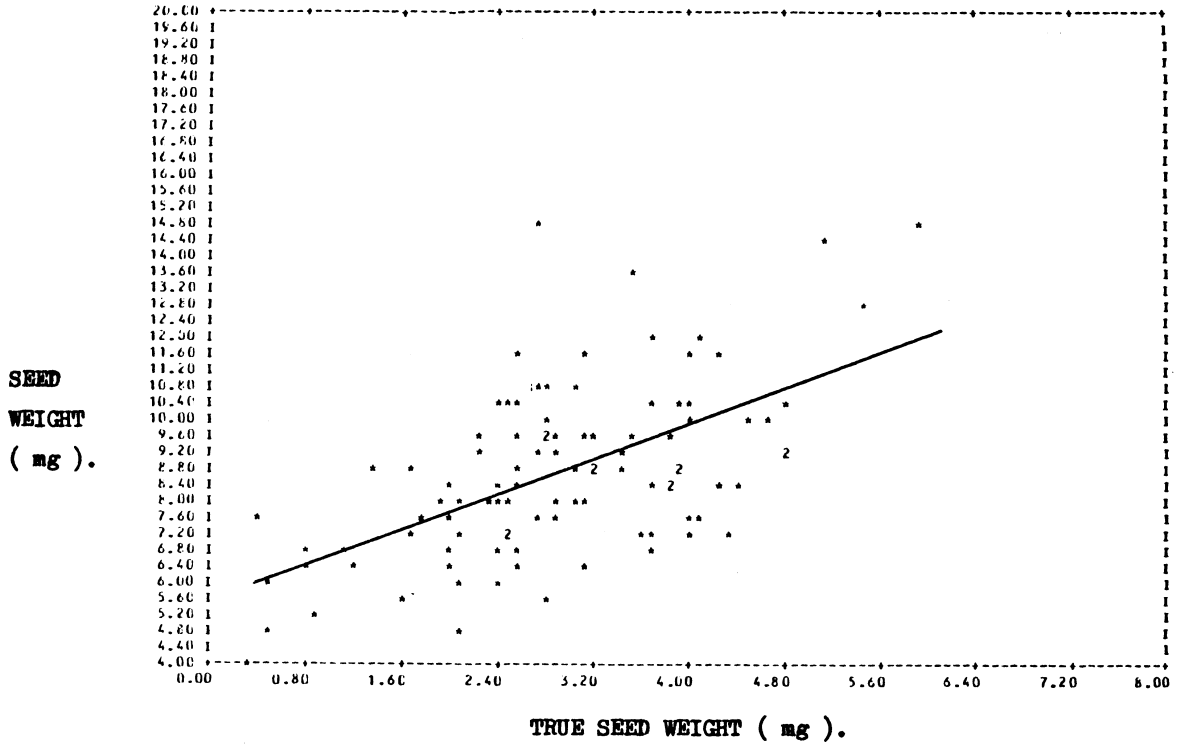


FIGURE 2: THE RELATIONSHIP BETWEEN SEED WEIGHT AND TRUE SEED WEIGHT FOR SEEDLOT 2. LINEAR REGRESSION: $Y = 1.09 X + 5.49$ WHERE Y IS SEED WEIGHT AND X IS TRUE SEED WEIGHT. CORRELATION: 0.5872 (SIGNIFICANT AT $P = 0.001$)

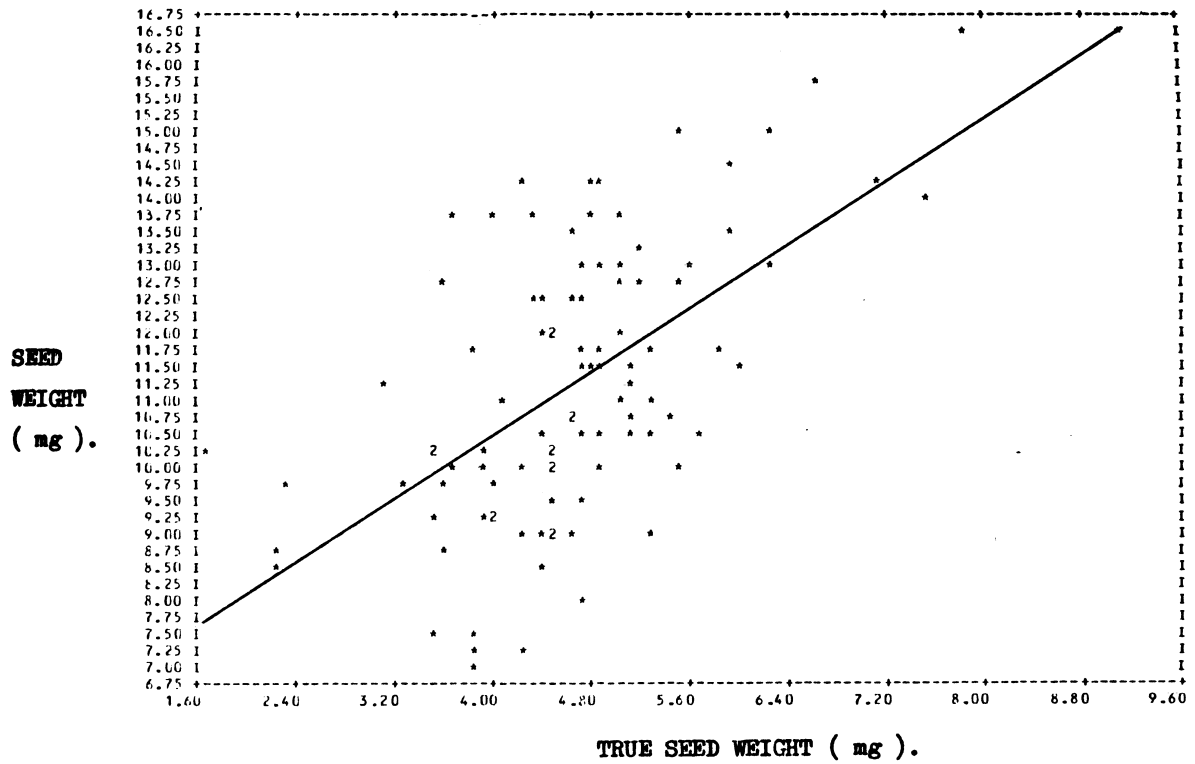


FIGURE 3: THE RELATIONSHIP BETWEEN SEED WEIGHT AND TRUE SEED WEIGHT FOR SEEDLOT 3. LINEAR REGRESSION: $Y = 1.19 X + 5.72$ WHERE Y IS SEED WEIGHT AND X IS TRUE SEED WEIGHT. CORRELATION: 0.6101 (SIGNIFICANT AT P = 0.001)

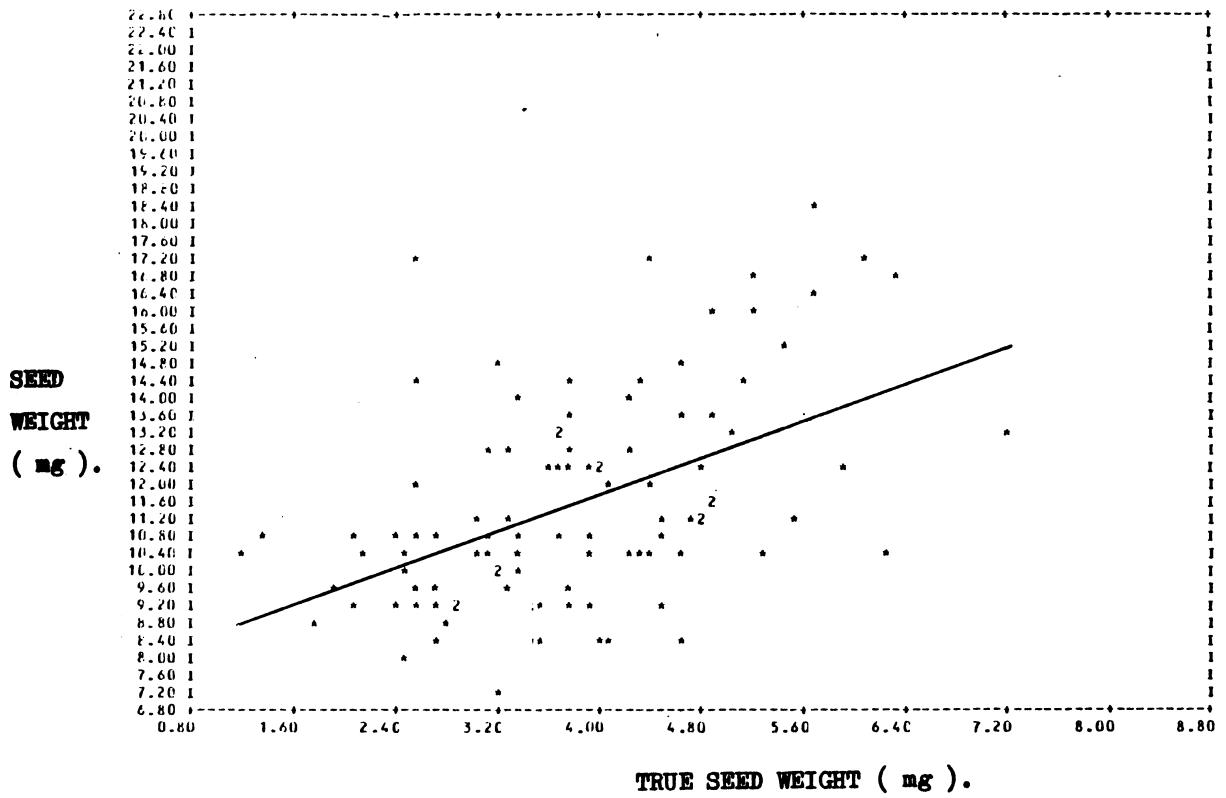


FIGURE 4: THE RELATIONSHIP BETWEEN SEED WEIGHT AND TRUE SEED WEIGHT FOR SEEDLOT 4. LINEAR REGRESSION: $Y = 1.06 X + 7.55$ WHERE Y IS SEED WEIGHT AND X IS TRUE SEED WEIGHT. CORRELATION: 0.502 (SIGNIFICANT AT $P = 0.001$)

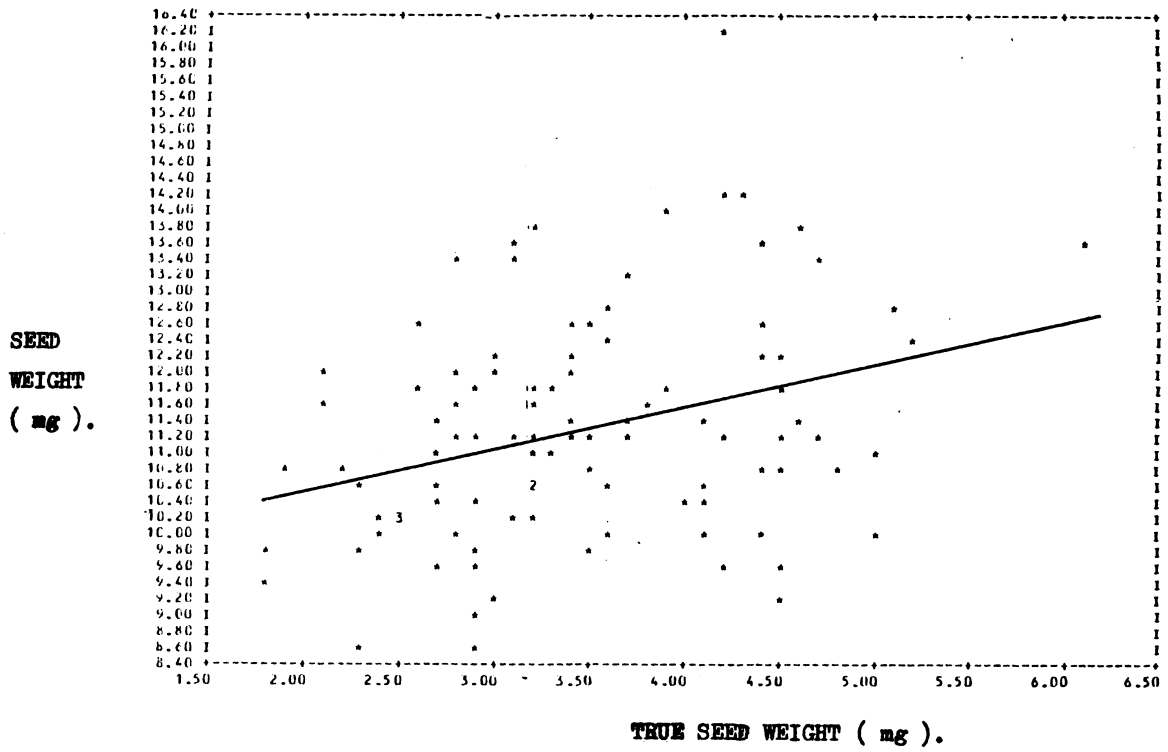


FIGURE 5: THE RELATIONSHIP BETWEEN SEED WEIGHT AND TRUE SEED WEIGHT FOR SEEDLOT 4. LINEAR REGRESSION: $Y = 0.521 X + 9.48$ WHERE Y IS SEED WEIGHT AND X IS TRUE SEED WEIGHT. CORRELATION: 0.329 (SIGNIFICANT AT $P = 0.01$)

germination times (M.G.T.) with least significant differences at $P \geq 0.05$ are presented in Tables 2 & 3. The formula used to calculate the M.G.T. for individual replicates was:-

$$(M.G.T.) = \frac{\Sigma(G \times T)}{F}$$

Where T = the day on which germination count was made

G = the number of seeds germinated on the day of the count

F = final number of seeds which germinated in each replicate

This formula was used in all germination experiments (Battle & Whittington 1969a).

All significant differences referred to in this section and thereafter unless otherwise indicated are at significance level $P \geq 0.05$.

The six germination tests were carried out over a period of time and therefore direct comparison of seed lots across experiments is not valid. Statistical analyses were only carried out within each germination test.

The first germination test (Experiment 1) carried out under standard (i.e. optimal) conditions for germination showed that seed lots 1, 2, 3 & 4 had almost completed germination after four days, while Lot 5 had an extended germination period ([Figure 6](#)). Lots 1, 3 & 4 reached higher final germination percentages than Lots 2 & 5 ([Table 2](#)). Lot 2 was significantly lower than Lots 1, 3 & 4 and Lot 5 was significantly lower than Lot 2.

The most rapid germination occurred with Lots 3 & 4 which were not significantly different from each other ([Table 3](#)). Lots 1 2 & 5 however,

TABLE 2: FINAL GERMINATION PERCENTAGES IN
SIX EXPERIMENTS

KEY P = 0.05 *, P = 0.01 **, P = 0.001 ***

SIGNIFICANCE LEVEL SL,

LEAST SIGNIFICANT DIFFERENCE LSD,

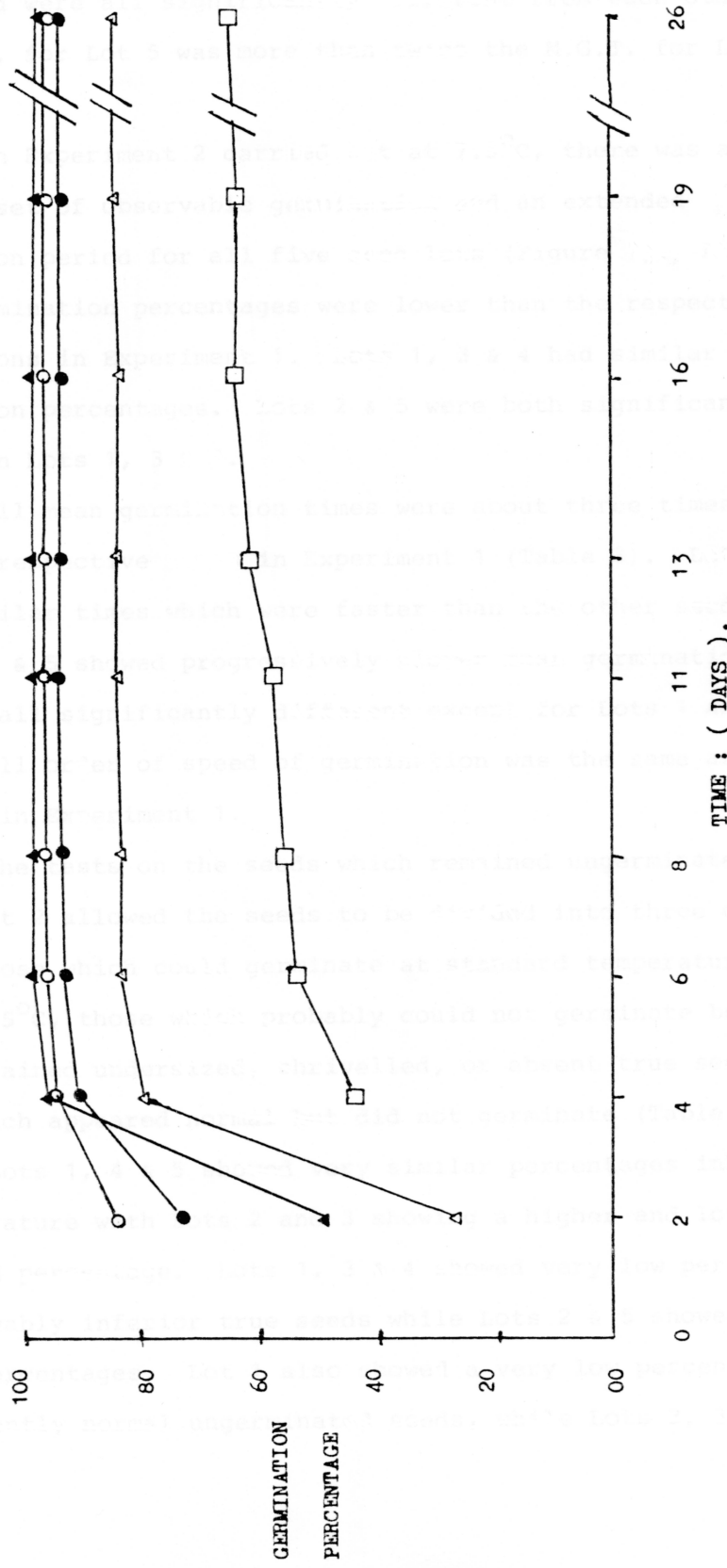
STANDARD ERROR DIFFERENCE SED.

EXPERIMENT	SEED LOT					SED	LSD @ P = 0.05	SL
	1	2	3	4	5			
1. Standard test	97.5	84.0	93.0	95.0	65.0	2.63	5.72	***
2. Constant 7.5°C	82.5	63.5	82.5	81.0	61.0	5.24	11.43	***
3(i). Advanced, standard temperatures	95.0	88.5	-	-	82.0	2.74	7.75	**
3(ii). Advanced, constant 7.5°C.	93.5	78.5	95.0	92.5	76.0	4.89	10.65	**
4. GA ₃ in petri-dish	93.0	83.0	96.5	97.5	79.0	2.49	5.42	***
5. GA ₃ Advanced, standard temperatures	95.5	88.0	-	-	81.0	4.10	10.01	*

TABLE 3: MEAN GERMINATION TIMES (DAYS), IN 6 EXPERIMENTS

KEY P = 0.001 ***, SIGNIFICANCE LEVEL SL,
LEAST SIGNIFICANT DIFFERENCE LSD,
STANDARD ERROR DIFFERENCE SED.

EXPERIMENT	SEED LOT					SED	LSD @ P = 0.05	SL
	1	2	3	4	5			
1. Standard test	3.06	3.71	2.57	2.34	6.23	0.283	0.616	***
2. Constant 7.5°C	11.00	12.54	9.78	9.28	16.85	0.639	1.390	***
3(i). Advanced, standard temperatures	2.15	2.79	-	-	4.94	0.216	0.528	***
3(ii). Advanced, constant 7.5°C.	3.61	4.24	4.36	4.21	7.29	0.248	0.540	***
4. GA ₃ in petri-dish	2.43	3.30	2.29	2.42	6.37	0.316	0.688	***
5. GA ₃ Advanced, standard temperatures	1.37	2.18	-	-	3.70	0.134	0.327	***



KEY : Lot One (▲); Lot Two (△); Lot Three (●); Lot Four (○); Lot Five (□).
FIGURE 6 : GERMINATION PATTERN OF FIVE SEEDLOTS UNDER STANDARD GERMINATION TEST CONDITIONS.

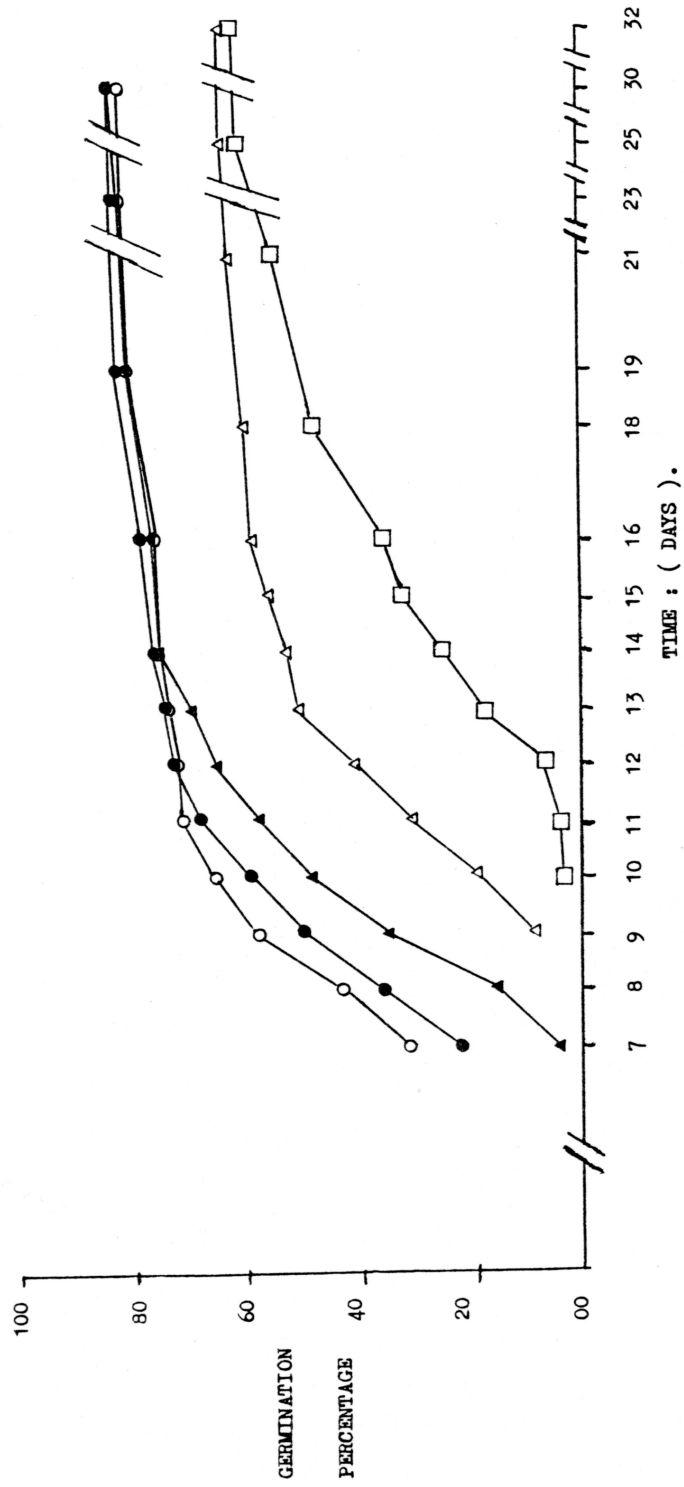
respectively showed progressively slower mean germination times, and were all significantly different from each other. The M.G.T. for Lot 5 was more than twice the M.G.T. for Lots 3 & 4.

In Experiment 2 carried out 7.5°C, there was a delay in the onset of observable germination and an extended germination period for all five seed lots (Figure 7). All final germination percentages were lower than the respective germinations in Experiment 1. Lots 1, 3 & 4 had similar final germination percentages. Lots 2 & 5 were both significantly lower than Lots 1, 3 & 4.

All mean germination times were about three times longer than the respective times in Experiment 1 (Table 3). Lots 4 & 3 had similar times which were faster than the other seed lots. Lots 1, 2 & 5 showed progressively slower mean germination times and were all significantly different except for Lots 1 and 3. The overall order of speed of germination was the same as that obtained in Experiment 1.

The tests on the seeds which remained ungerminated from Experiment 2 allowed the seeds to be divided into three categories viz:- those which could germinate at standard temperature but not at 7.5°C, those which probably could not germinate because they contained undersized, shrivelled, or absent true seeds and those which appeared normal but did not germinate (Table 4).

Lots 1, 4 & 5 showed very similar percentages inhibited by temperature with Lots 2 and 3 showing a higher and lower inhibited percentage. Lots 1, 3 & 4 showed very low percentages of observably inferior true seeds while Lots 2 & 5 showed higher percentages. Lot 1 also showed a very low percentage of apparently normal ungerminated seeds, while Lots 2, 3 & 4



KEY : Lot One (▲); Lot Two (△); Lot Three (●); Lot Four (○); Lot Five (□).

FIGURE 7 : GERMINATION PATTERN OF FIVE SEEDLOTS UNDER LOW TEMPERATURE CONDITIONS
(CONSTANT 7.5°C).

TABLE 4: ADDITIONAL DETERMINATIONS ON SEEDS WHICH
FAILED TO GERMINATE AT 7.5°C IN EXPERIMENT 2

CHARACTERISTIC	SEED LOT				
	1	2	3	4	5
1. Seeds inhibited by low temperature in Expt 2 (%) 2.	13.5	21.5	9.0	13.0	14.0
2. Empty & shrivelled seeds (%)	2.0	7.0	0.5	1.0	5.5
3. Maximum potential germination (100 - % empty & shrivelled seeds)	98.0	93.0	99.5	99	96.5
4. Other ungerminated seeds in Expt 2	2.0	8.0	8.0	5.0	19.5
5. Summed germination, (7.5°C + standard temperatures) in Expt 2 (%)	96.0	85.0	91.5	94.0	75.0

showed higher percentages. Lot 5 was considerably higher than the others.

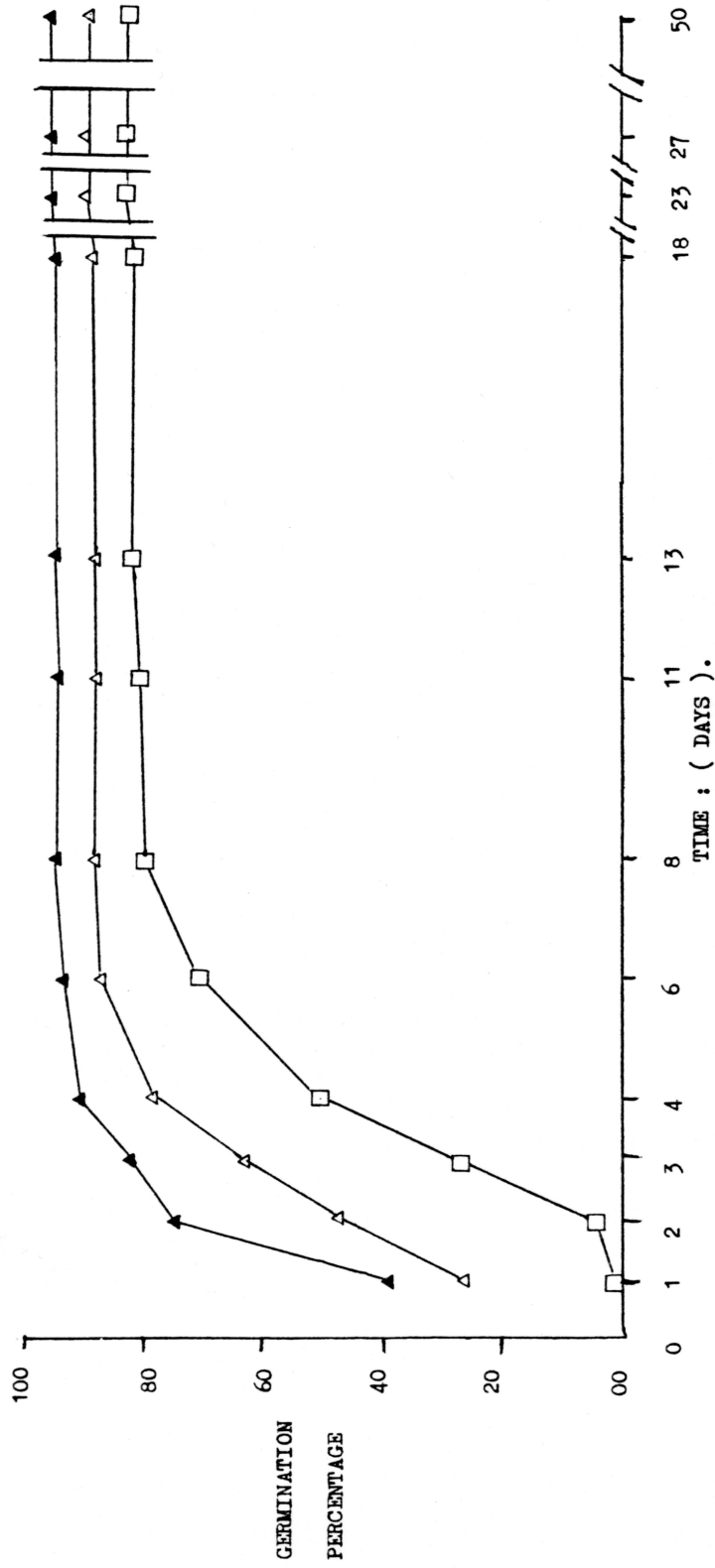
When the respective temperature inhibited germinations are added to the final germinations obtained in Experiment 2, the sum of the germinations are very similar to the final values obtained in Experiment 1, except for Lot 5 which is 10% higher.

In Experiment 3 (i) carried out at standard temperatures with seed advanced in water, there were no large improvements in the final germinations compared with Experiment 1, except with Lot 5 which reached a substantially higher germination (Figure 8). Lot 1 produced significantly more germinated seeds than Lot 5, but Lot 2 which had an intermediate value was not significantly different from either of these lots (Table 2). Mean germination times were all significantly different and faster than the respective times obtained in Experiment 1 (Table 3). Lot 1 had the shortest germination time and Lot 5 the longest.

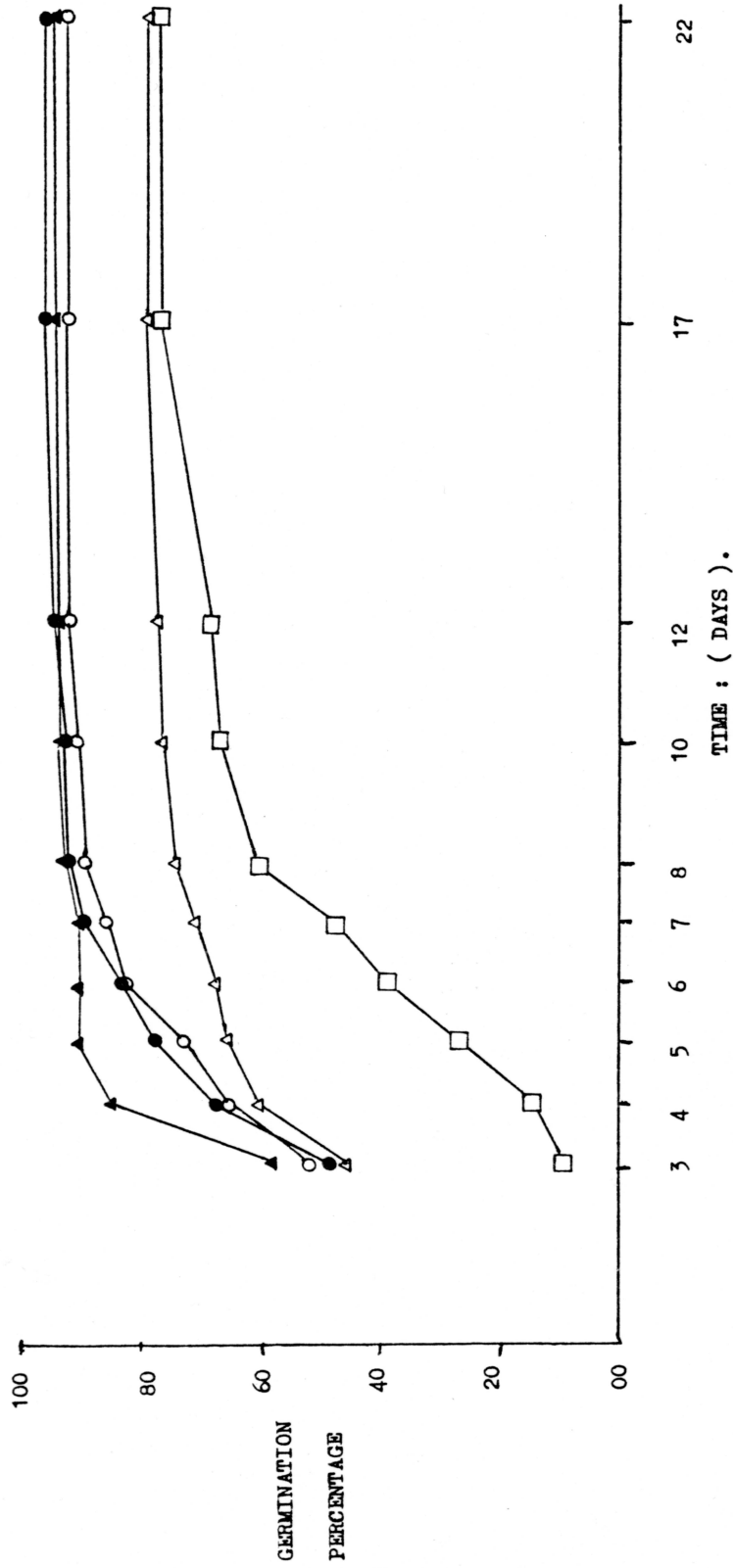
Experiment 3 (ii) carried out at 7.5°C, with seed advanced in water, produced lower final germination percentages than those obtained in Experiments 1 and 3 (i), except for Lots 3 & 5 which produced more germinated seeds in this experiment than in Experiment 1 (Figure 9).

However, all respective final germinations were greater than those obtained in Experiment 2, (also run at 7.5°C). Lots 1, 3 & 4 produced similar values under these conditions. Lots 2 & 5 produced significantly lower germination values than the other three but were not significantly different from each other (Table 2).

All mean germination times were longer than the respective times in Experiments 1 & 3 (ii) but shorter than the respective times in Experiment 2. The germination time for Lot 1 was significantly shorter than Lots 2, 3 & 4.



KEY : Lot One (▲); Lot Two (△); Lot Five (□).
FIGURE 8 : GERMINATION PATTERN OF THREE SEEDLOTS (ADVANCED IN WATER) UNDER
STANDARD GERMINATION TEST CONDITIONS.



KEY : Lot One (▲); Lot Two (△); Lot Three (●); Lot Four (○); Lot Five (□).

FIGURE 9 : GERMINATION PATTERN OF FIVE SEEDLOTS (ADVANCED IN WATER) UNDER LOW TEMPERATURE CONDITIONS (CONSTANT 7.5°C).

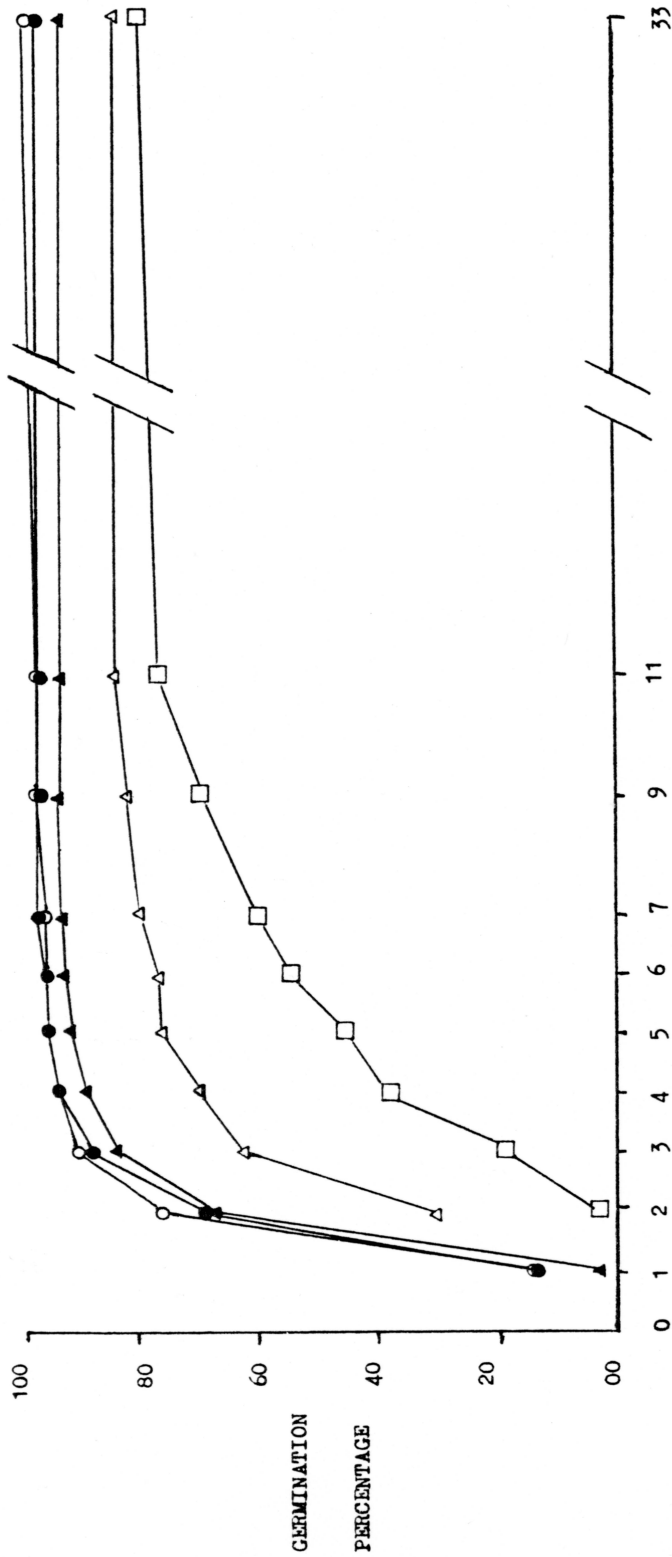
which were not significantly different from each other. The time for Lot 5 was significantly longer than all the other Lots (Table 3).

In Experiment 4 carried out at standard temperatures with GA₃ solution in the petri-dishes, the final germination percentages were very similar to the respective figures obtained in Experiment 1 (Figure 10). However, Lot 5 reached a considerably higher germination percentage than in Experiment 1. As in other experiments Lots 1, 3 & 4 were very similar, and Lots 2 & 5 were significantly lower than the other 3 (Table 2).

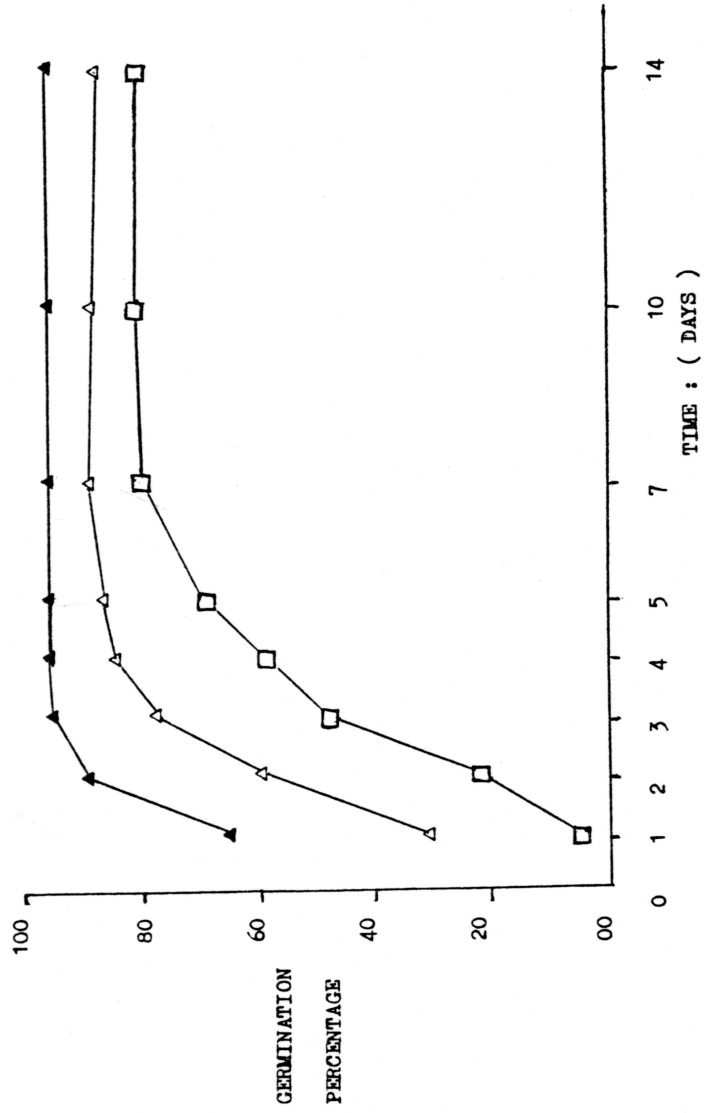
Mean germination times were also similar to the respective times obtained in Experiment 1. Lots 1, 2 & 3 had slightly shorter times, and Lots 4 & 5 slightly longer times in this experiment. The shortest mean germination times were obtained with Lots 1, 3 & 4, which were not significantly different from each other. Lot 2 had a significantly longer time than Lots 1, 3 & 4; Lot 5 a significantly longer time than Lot 2 (Table 3).

The final germination test (Experiment 5) run at standard temperatures with seed advanced in GA₃ solution, (Figure 11) showed final germination percentages very similar to the respective germination percentages obtained in Experiment 3 (i) (seed advanced in water at standard temperatures). Lot 1 reached a significantly higher final germination than Lot 5, but Lot 2, which was intermediate, was not significantly different from either Lot used in this experiment (Table 2).

All mean germination times were faster than the respective times obtained in Experiment 3 (i). The time for Lot 1 was significantly faster than the time for Lot 2, which was significantly faster than the time for Lot 5 (Table 3).



KEY : Lot One (▲); Lot Two (●); Lot Three (△); Lot Four (○); Lot Five (□).
FIGURE 10 : GERMINATION PATTERN OF FIVE SEEDLOTS (WITH GA₃ SOLUTION IN PLACE OF DISTILLED WATER IN THE PETRI DISHES), OTHERWISE UNDER STANDARD GERMINATION TEST CONDITIONS.



KEY : Lot One (▲); Lot Two (△); Lot Five (□).

FIGURE 11 : GERMINATION PATTERN OF THREE SEEDLOTS (ADVANCED IN Ca_3 SOLUTION)
UNDER STANDARD GERMINATION CONDITIONS.

3.2.3 The Emergence Test

The results from the emergence test are presented in Table 5. The emergence percentages, from compost, of all the seed lots, were all lower than the standard germination test data recorded in Experiment 1. This reduction was most evident in seed lots 2 - 5 where the magnitude of the reduction was 20-42%.

The majority of the seedlings emerged before the 16 day count with only small numbers emerging in the final 11 day period. However, with Lots 2 and 4 a further increase of 10-11% was recorded indicating a higher proportion of late germinations in these Lots. After 16 days, Lot 1 produced significantly more seedlings than all other Lots. Lots 4 and 5 produced the lowest emergence percentages and were both significantly lower than Lot 3. The values for Lot 2 were intermediate between Lots 4 and 5, and Lot 3. The relative emergence values for the seed lots after 27 days were similar to those after 16 days.

Average seedling dry weights were highest for Lot 1 and those from Lot 5 were lowest, being approximately half the weight of Lot 1. The weights from Lots 2, 3 and 4 were all similar and intermediate between Lots 1 and 5. The total seedling dry weights per tray after 16 days reflected differences between seed lots in seedling numbers and average dry weights.

3.2.4 The effect of water soluble seed extracts on cress seed germination

The data presented in Table 6 are the mean values of the 0.5 and 0.25 dilution extracts, as the 0.1 and 0.01 dilution did not produce detectable inhibitory effects, and there was insufficient extract to replicate the

TABLE 5: EMERGENCE % AND SEEDLING DRY WEIGHTS IN EXPT 6
(EMERGENCE TEST), COMPARED WITH STANDARD GERMINATION TEST

KEY P=0.001***, SIGNIFICANCE LEVEL SL

LEAST SIGNIFICANT DIFFERENCE LSD.

STANDARD ERROR DIFFERENCE SED.

EXPERIMENT	SEED LOT					SED	LSD @ P = 0.05	SL
	1	2	3	4	5			
Standard Germination % (Expt 1)	97.5	84.0	93.0	95.0	65.0	2.64	5.72	***
Emergence at 16 Days	88.3	58.0	68.5	42.3	51.8	5.57	12.13	***
Emergence at 27 Days	92.0	68.5	73.0	53.5	57.3	4.01	8.74	***
Total Dry Weight per Tray at 16 Days (g)	1.85	0.90	1.05	0.70	0.57	0.12	0.25	***
Average Dry Weight per Seedling at 16 Days (mg)	21.0	15.7	15.4	16.9	10.9	1.66	3.62	***

TABLE 6: THE INHIBITORY EFFECTS OF BEET SEED

EXTRACT ON CRESS SEED GERMINATION

	Water Control	Lot 1 Extract	Lot 2 Extract	Lot 5 Extract
Cress Final Germination (%)	99	98.5	97	97.5
Mean Germination Time (Days)	1.23	1.74	2.13	2.06
Relative Mean Germination Time	100	141	173	166

undiluted extract test. The beet extracts had little if any effect on final germinations, but a considerable effect on mean germination time. The Lot 2 extract had the most inhibitory effect compared with the water Control and the extract of Lot 1 the least. The Lot 5 extract was slightly less inhibitory than the Lot 2 extract.

3.3 Discussion

3.3.1 Germination tests at standard temperatures and 7.5°C with untreated seed

The results of the standard germination test (Expt 1), show that considerable variation exists between Monogerm sugar beet seed lots, in germination performance, even though the test conditions were intended to be ideal for germination. There must therefore be inherent seed factors influencing the observed performances, which make beet germination tests of relatively low precision, as earlier found by Hibbert & Woodwark (1969).

This was confirmed at the end of the experimental period when Expt 1 was repeated. Lot 5 reached a final germination 18% higher in the re-test while the other seed lots did not differ by more than 7.5%.

Inherent variation in seed lots limits the value of comparisons between tests and treatments, but generalised conclusions can be made.

Two of the three lots which exceeded 90% germination in Expt 1 had been commercially processed, and also had fast M.G.T. values but as both processed and unprocessed samples of the same seed lot were not available for comparison, it cannot be confirmed that processing improves seed performance.

The results of Expt 2 clearly indicate that in all seed lots germination proceeds at a slower rate at 7.5°C than at standard temperatures. The extended period of germination and the lower final germinations recorded indicate a variation in individual seeds within seed lots in germination performance at 7.5°C.

This test is therefore measuring an aspect of seed vigour in the seed lots i.e. the ability to germinate at less than optimal temperatures. The M.G.T. values and the number of seeds which subsequently germinated when the petri-dishes were incubated at standard temperatures could be used to quantify this.

The amount of temperature inhibition of germination observed in the seed lots was considerably less than the values observed by Brown (1980) working at lower temperatures (5-7°C) with several seed lots. Scott et al (1973) showed that Sharpes Klein E was markedly inhibited at 5°C and severely so at 3.5°C in germination tests and also emerged poorly when sown early into a cold soil. This shows that beet seed germination is very sensitive to temperature over the range 3.5 - 7.5°C. Further work in this area would be of value for breeding, i.e. selecting for low temperature germination and also for testing the low temperature performance of existing varieties.

The dissection of the remaining ungerminated seeds from Expt 2 showed that as the rubbed Lots 2 5 contained more empty and shrivelled true seeds their maximum potential germination would have been lower than the other lots. It was assumed that these seeds were incapable of germination as they had been in the petri-dishes for over fifty days. This assumption may not hold for all seeds as Scott et al (1972) showed that underdeveloped seeds steeped in water or GA₃ solution emerged better than untreated seeds.

When the seed lots are compared on a maximum potential germination basis i.e. comparing the number of other ungerminated seeds, Lot 2 is similar to Lots 1, 3 & 4. If processing could successfully remove the empty and shrivelled seeds, Lot 2 would have performed better in Expt 1. Lot 5 however, contained a high number of seeds which failed to germinate for other reasons as well as seeds which were empty or shrivelled. Therefore Lot 5 would not have performed well in Expt 1 even if the empty and shrivelled seeds had been removed by processing.

The poor performance of Lot 5, i.e. low final germination and slow M.G.T. at both standard temperatures and 7.5°C may have been due to the inhibitor content of the seed coat, but the extract from Lot 5 was actually slightly less inhibitory than the extract from Lot 2 on cress M.G.T. However, the exact chemical nature of the extracts was not determined and cress and beet seed may respond differently to different inhibitors.

The effects of inhibitors could have been removed from the tests by careful (dry) excision of true seeds or alternatively removal of the seed coat by a dentist's drill as used by Battle & Whittington (1969b). This method improved final germination and speed of germination of a seed lot but in addition to removing the effects of inhibitors, less energy would be required for germination and more oxygen would be accessible to the true seed. The effects of inhibitors would therefore be over-estimated by this method, but it reveals that physical factors of the seed coat can also influence germination.

The number of tight seed caps on seeds could be one such physical factor involved in the performance of Lot 5, as the seed lots differed in the amount of seed caps lost in the advancing procedure. The rubbed lots lost few compared with the processed.

The effects of chipping the seed cap before testing are discussed in Section 2.3.5.

Another possible explanation is that seed deterioration had occurred, but the viability of beet seed is retained over long periods of storage (Section 2.3.2) and the re-tested germination of Lot 5 under standard conditions implies that the performance has improved with time. This is unlikely in 5 year old seeds and no similar observation was recorded with Lot 2 which was also 5 years old.

3.3.2 Seed characteristics

The weight determinations show that there is considerable variation in both seed and true seed weights in the seed lots even when a good linear relationship exists between them. Unfortunately germination performance and seed weights cannot be inter-related in this investigation as the dissections in Expt 2 were not weighed and no size/weight gradings were used for selecting seed for the germination tests.

The effects of seed size on emergence are described in Section 2.4.7. It is also probable that larger seed within a seed lot will germinate better, whether processed or not (Scott et al 1974). Grading by diameter or weight would have been of value in explaining differences between the germination performance of the seed lots. However, more meaningful information could be obtained if true seed sizes were related to performance and possibly vigour. Techniques such as Radiography (Longden et al 1970) would be required for this.

The mean proportions of the seed as true seed of 4 of the seed lots were about 8% higher than those obtained for rubbed seed by Scott et al (1974) for several seed lots and about 14% higher than the mean for all seed lots (natural and rubbed)

determined by Scott et al (1974). Mean proportions would tend to increase after rubbing as it is part of the pericarp and not the true seed that is removed. However, it is not possible to determine exactly how much material is removed by rubbing as no natural seed of any of the seed lots used were available for this investigation.

The other seed lot (Lot 3) had a greater proportion of the seed as true seed probably because of the high mean true seed weight and not due to severe rubbing but this cannot be confirmed.

The true seed weights are however considerably higher than those determined by Savitsky (1954) working with early monogerm material. Savitsky predicted that true seed weights could be increased genetically and improvements in husbandry and grading techniques may also have contributed to this objective.

3.3.3 Germination tests with treated seed

None of the treatments used in this investigation noticeably improved final germination at standard temperatures in any of the seed lots with the possible exception of Lot 5 when compared with Expt 1. If however, the re-tested final germination for Lot 5 is used there would appear to be no improvement in final germination of Lot 5 by treatments. No determination has satisfactorily explained the performance of Lot 5, therefore it may differ from the other lots in some unknown way in response to treatments but being poorer than the other lots, a greater capacity for improvement by any treatment might be expected.

It can however be concluded, at least for the other seed lots, that at standard temperatures in petri-dishes with adequate water, GA₃ solution, Advancing with water and Advancing with GA₃ solution cannot encourage seeds to germinate which could not do so without treatment.

The treatments did however shorten mean germination times by different amounts. The following is an attempt to explain the observations.

1. The GA₃ solution in the dishes must have accelerated the physiological development of the germination process in at least some of the seeds so that radicle emergence was observed earlier than in Expt 1.
2. The mean germination times for seed advanced in water, which were even faster than the GA₃ solution in the petri-dishes, would be due to early stages in the physiological development of the germination process occurring during the advancing procedure. Physiological development can be quantified by assessing cell division and Longden (1971) showed that this occurs in the advancing procedure. Cell division must also occur in untreated seed in the petri-dish before radicle emergence but as cell division and other physiological processes take time and can only occur in imbibed seed, seeds which are partially developed (i.e. advanced) before being placed in the petri-dishes should take less time than untreated seeds, to reach radicle emergence, i.e. observable germination.
3. The combination treatment Advancing with GA₃ solution resulted in faster M.G.T. values than the water advancing treatment due to the accelerating effects

of GA₃ on the physiological development of germination both during the advancing procedure and in the petri-dishes thereafter, or in at least one of these phases.

The effects of GA₃ and Advancing on the rubbed seed lots can now be compared, as shown in Table 7.

TABLE 7: THE RELATIVE EFFECTS OF SEED TREATMENTS ON MEAN GERMINATION TIMES (M.G.T.)

EXPERIMENT	Lot 1		Lot 2		Lot 5	
	MGT (Days)	% of Expt 1	MGT (Days)	% of Expt 1	MGT (Days)	% of Expt 1
1. Standard Test	3.06	100	3.71	100	6.23	100
3 (i). Water Advancing	2.15	70.3	2.79	75.2	4.94	79.3
4. GA ₃ Solution in petri-dishes	2.43	79.4	3.3	88.9	6.37	102.2
5. GA ₃ Advancing	1.37	44.8	2.18	58.7	3.70	59.4

Although GA₃ solution in the petri-dishes is not strictly compatible with water Advancing for addition, to compare with GA₃ Advancing, the combination treatment shows a greater reduction in the M.G.T. values of the 3 lots than either of the individual treatment reductions, or the sum of the 2.

This incompatibility, lack of precision and because the experiments were carried out at different times precludes determination of whether the effects are additive or synergistic (Longden 1976).

The anomalous result of GA₃ apparently slowing down the germination of Lot 5 may have arisen by chance but possibly Lot 5 responds differently to treatments such as GA₃, as suggested earlier in this section.

Clearly this set of experiments was inadequate to explain the nature of the effects of GA₃ and Advancing. A larger experiment which included the following additional treatments would be required to elucidate the situation.

1. Water advancing plus GA₃ in the petri-dishes.
2. GA₃ Advancing plus GA₃ in the petri-dishes.
3. GA₃ Advancing followed by thorough washing before testing.
4. Thorough washing of untreated seed before testing.

These extra tests would be necessary to identify which stages of the germination process are accelerated by GA₃. In addition some investigation of endogenous levels in the seed and responses to concentration of GA₃ and other growth regulators would be of assistance.

The processed seed lots (Lots 3 & 4) which were advanced in water after removal of the pelleting material however showed the shortcomings of multi-treatments involving solutions, where loss of the seed cap occurred with many of the seeds (Longden 1976). If advancing were to be used in practice it would be carried out before the pelleting procedure or in combination with fluid drilling and loss of seed caps may not be such a serious problem (Longden et al 1979).

In this investigation however, the definition used for germination was unsuitable for advanced processed seed. The seeds which had lost seed caps in the advancing procedure were excluded from the germination tests and this was a high proportion of the processed seed lots. Presumably it was the faster germinating seeds which were removed and therefore the reduction in M.G.T. values of the processed seed lots were under estimated in this investigation by the bias of selecting slower germinating seed. That Lots 3 & 4 should lose more seed caps than the rubbed lots is in agreement with the faster M.G.T. values obtained for the processed lots in Expt 1.

An improved germination definition for advanced seed in tests could be to consider only seeds with radicles > 5 mm as germinated and others with or without caps as ungerminated. Fewer seeds would be excluded after advancing. However, this definition would have to be used in all other experiments for fair comparison. Mean germination times would be longer than if the original definition was used in any one test situation.

A further area in which experimentation could be continued would be in determining if the advancing technique in terms of seed: solution ratios, number of cycles and temperature were optimal. The effect of advancing on inhibitors could also have been investigated by taking extracts of advanced seed and assaying this on cress germination.

The test with water advanced seed, in petri-dishes at 7.5°C (Expt 3ii) showed that advancing almost completely removed the low temperature inhibition of germination observed in Expt 2. This implies that there is a critical stage which is inhibited in some seeds but once passed, then germination can proceed at 7.5°C . Some kind of priming must be occurring in the advancing procedure. The M.G.T. values in this test were faster than in

Expt 2 (untreated seed at 7.5°C) as physiological development had occurred before the test commenced as described earlier for advancing and testing at standard temperatures. However, M.G.T. values were not as fast as those obtained with untreated seed at standard temperatures in Expt 1.

Further low temperature tests with GA₃, Advancing and GA₃ Advancing would have been valuable as Scott *et al* (1972) predicted GA₃ effects were more noticeable at low temperatures and may be of practical value.

3.3.4 The emergence test

This test (Expt 6) showed that even at warm temperatures in a glass house sugar beet emergence was erratic and often much lower than the standard germination test.

The emergences of two of the lots, 4 & 5 (Amono and Nomo) were actually lower after 27 days than the values obtained in field trials (NIAB 1980) indicating that the test may have been terminated before maximum emergence occurred. However, if it is assumed that the potential emergence is equal to the germination recorded in the standard test then varying numbers of seeds fail to produce seedlings. Thus the emergence test was effectively measuring another aspect of seed vigour, i.e. the ability of a seed lot to produce healthy seedlings within 27 days at 16°C in compost. Both emergence and seedling weights could be used to assess this. This vigour test would not be of value for field conditions on its own but if similar tests run at lower temperatures were also carried out, possibly temperature inhibition could be removed from the effects of soil factors influencing emergence.

More information about seeds which failed to emerge could have been obtained by carefully searching the compost to determine, a) the number of ungerminated seeds b) the number which germinated and died c) the number which probably would have emerged if left for longer or d) the number showing abnormal development.

In this investigation there was insufficient data to attempt to reliably predict emergence from the germination tests as Brown (1980) calculated.

3.3.5 Conclusion

The experiments carried out in this investigation have confirmed the difficulties involved in testing beet seed due to its inherent variability in size, inhibitor levels and other factors.

The seed treatments used shortened mean germination times at standard temperatures and also at low temperatures. The following general discussion considers the possible uses of the finding of the experiments for improving establishment in the field.

4. GENERAL DISCUSSION: THE POTENTIAL OF SEED
TREATMENTS TO IMPROVE FIELD ESTABLISHMENT

The factors involved in the establishment of sugar beet have already been described and discussed. The main reasons for poor establishment in the field, other than seed factors are; inadequate seedbed preparation, poor drill performance, pests and diseases, and low spring temperatures.

More efficient utilization of incident radiation could be achieved by improvements in general husbandry or breeding of better varieties, resulting in more regular stands and earlier complete leaf coverage. However this discussion is mainly concerned with methods of improving establishment directly related to the seed used at present. In all cases the final objective is an increase in sugar yields.

The "drilling to a stand" technique as used in the U.K. normally requires at least 70% of all seeds sown to produce healthy plants to prevent yield reductions due to "gappiness" and justify use of the technique (Hull and Jaggard 1971).

A recent survey showed that, in 1980, most fields did achieve emergences greater than 70% although the range was 20-90% (Durrant 1980). Soil texture influenced emergence with loams and clays producing inferior stands compared to organic, silty and sandy soils. Seed excavations in some of the fields in the survey revealed that germination in the field was similar to the laboratory determination and where emergence was low it was due to subsequent death of germinated seeds caused by drought, shallow sowing, cobbly seedbeds or by mice excavations. Although this is only one relatively small reported investigation it implies that post germination factors are more important in reducing establishment, in contrast with the factors categorised by Aura (1975, Section 2.4.5).

The standard commercial seed processing procedure also implies that seed vigour is a limiting factor, as seed lots of high germination can be produced, and E.M.P. and methiocarb give protection to seedlings against some diseases and small pests. Additional control of millipedes and insects can be obtained by incorporating aldicarb or carbofuran granules in the seedbed (Durrant 1980). However although protection of seedlings may reduce "gappiness", faster emergence, the objective of the seed treatment used in the germination experiments in this investigation, is not encouraged.

Longden et al (1979) reported an extensive investigation into the effects of various priming, steeping and advancing pre-treatments. Some of these treatments were discussed in Section 2.2.8. None of the treatments gave significant responses in sugar yield compared with untreated seed as used in practice, despite a 30-50% increase in seedling weights during May and June in the field. This compares with a 100 fold weight difference between untreated seed and transplanted seedlings of multigerm varieties in June which resulted in a 28% (10 T/ha) increase in root yield (Scott & Bremner 1966).

The considerable amount of time and effort involved in treating the seeds (all involved many hours in solutions) with no guarantee of an improved yield resulted in Longden et al (1979) rejecting them as feasible alternatives to the standard procedure.

The advancing treatments, with or without GA₃ solution, used in the germination tests in this investigation would probably be rejected on similar grounds even without field trials. However, the GA₃ solution in the petri-dishes, although giving a smaller reduction in M.G.T. values and being less consistent in effect than advancing, allows GA₃ solution to be

in contact with true seeds. Contact with the true seed is necessary for acceleration of the physiological development of the germination process.

A method of allowing access of GA₃, or another suitable growth regulator, to the true seed in 'the field is required. This could be achieved by mixing a relatively high concentration of GA₃ solution with the E.M.P. steep in the standard processing procedure. A high concentration would be required, as the steep has to be of short duration (twenty minutes) to prevent mercury penetrating the true seed (Lindsay 1980, personal communication). Even if GA₃ only penetrated the seed coat during the steep, it should reach the true seed on imbibition in the field.

An alternative method would be to incorporate GA₃ in the pelleting material either in a layer close to the seed or spread throughout the coating (Longden 1975).

Germination tests and field trials with seeds treated with various steeping concentrations of GA₃ solution or different formulations in the pelleting material would be required to assess the yield response and any disadvantages, e.g. incompatibility with the standard process.

Seedlings from GA₃ treated seeds were found to be elongated and pale green by Scott et al (1972), but foliar application of GA₃ had generally favourable effects (Garrod 1974). The root sink was increased early in the growing season, facilitating more efficient partition of the products of photosynthesis, but complex interactions with other endogenous growth regulators were occurring.

Another area where seed could be improved is in the seed production field. Battle & Whittington (1969a) studied factors affecting the maturity of true seeds on the mother plant (Section 2.2.5). Rainfall or irrigation appeared to have both

beneficial and harmful effects. Washing out of inhibitors and seed advancing occurred (Longden, 1971, 1973, Section 2.2.8), but heavy rainfall probably associated with cooler temperatures, delayed maturity. Lower rainfall, probably associated with warmer temperatures, advanced the seed and hastened maturity.

Spraying seed crops with GA₃ or other suitable growth regulators may accelerate-maturity and/or advance seed by allowing GA₃ to contact the true seed on the mother plant. An early harvest of improved seed with less windshake losses could result, thus both root and seed growers could benefit. Experimentation would be necessary in this area.

Variation in rainfall on seed crops may advance seeds by different amounts, both on individual plants and in different seed growing regions. As seed is bulked and mixed in the processing procedure (Scott & Longden 1973) partial advancing by different amounts may explain some of the inherent variation in seed lots.

The potential uses of additional seed treatments can now be related to practicalities and costs. Seed processors would be unable to include Advancing or steeping procedures at a low cost to growers, unless a high demand existed, or if seeds of other crops could be treated simultaneously. Such a large scale requirement is unlikely to appear in the near future.

The grower however would only be interested in the yield response in relation to any additional costs of using treated seed. Assuming there are no other changes in variable costs, e.g. transport, gross margins would only be improved if every £1/ha addition to seed costs resulted in > 0.04 T/ha root yield. This calculation assumes that the price of 1 tonne of roots is £25.00 (NIX 1980). Treatment costs would probably be considerably more than £1/ha so that evidence of a reliable yield

response is essential before a grower would contemplate using additionally treated seed. The large variation in sugar beet yields between years (Biscoe et al 1980, Scott & Jaggard 1978) shows that such evidence is difficult to obtain. The search for any method of improving yield without extreme practical difficulty or high costs must therefore continue.

5. SUMMARY

The review of literature considers the production and processing aspects of monogerm sugar beet seed and the factors affecting its germination and field establishment.

The average fruit and true seed weights were determined and the relationship between them established for two commercial seed lots and three rubbed seed lots. There was a significant linear correlation between true seed and fruit weights ($r = 0.33 - 0.61$) of four of the seed lots although there was considerable variability. The mean proportion of fruit weight in the form of true seed weight was in the range 30% - 42%.

Under standard germination test conditions, the final germination percentage and mean germination time of two of the seed lots was markedly inferior to the other three. Under low temperature conditions (constant 7.5°C) germination percentages and mean germination times were adversely affected. Final germination percentages were 10 - 20% lower and mean germination times about 3 x longer than under standard conditions.

Seed treatments such as advancing in water or gibberellic acid (GA_3) solution, or adding GA_3 to the petri-dishes did not improve germination at standard temperatures but mean germination times were shortened. At 7.5°C water advancing improved germination and shortened mean germination times relative to untreated seed lots.

Emergence from compost in trays in a glass house was considerably lower than the standard germination test in four of the five lots including the commercial lots.

6. CONCLUSIONS

The laboratory germination performance of beet seed is extremely variable even under standard germination conditions. Mean germination times at standard temperatures can be shortened by seed treatments but final germination percentages are not affected. However final germinations can be improved at 7.5°C by advancing.

Improvements in germination performance by seed treatments are unlikely to produce yield responses large enough to economically justify use in practice. Cheap treatments therefore, fully compatible with the existing standard processing procedure must be developed to improve establishment and ultimately sugar yields.

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