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A STUDY OF SEED VIGOUR AND SEEDLING EMERGENCE OF  
MAIZE UNDER FIELD AND LABORATORY CONDITIONS

A thesis

presented in partial fulfilment of the requirements  
for the degree

of

MASTER OF AGRICULTURAL SCIENCE  
at  
MASSEY UNIVERSITY

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1973

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SUMMARY

The field experiment consisted of three soil conditions - crusted, wet and control. Crusted surface was obtained from over-cultivation and irrigation immediately before and after sowing then allowed to dry and develop a crust. Wet soil was obtained from over-irrigation during the early stages after sowing, up to 13 days. Two levels of vigour, high and low, were obtained by using the interim germination count for two varieties of maize, PX610 and XL45. The layout of the experiment was a split split plot design with four replications.

The results show that seedling emergence was not significantly affected by the soil conditions created in the crusted and wet plots even though emergence was higher in the control plots. However the growth of the seedlings at two weeks after planting was affected. Higher shoot dry matter, height, leaf area and root/shoot ratio was found in the control plots than in the crusted and wet plots. Growth was most severely affected by wet soil conditions, probably as the result of lack of aeration. The effect of soil conditions on growth disappeared at four weeks after planting. This may have been due to the improvement in soil moisture and aeration in the wet soil.

Variety PX610 showed higher ability to emerge and grow than XL45 right through the experimental period. It was found that wet conditions had a more marked effect on the growth of PX610 than XL45.

High vigour seed of PX610 performed better than low vigour seed but this was not the case with XL45.

A laboratory experiment was conducted after the field experiment to study the effect of soil moisture and temperature on seedling emergence and growth. The experiment consisted of three soil moisture levels of 12%, 18% and 22% of the soil taken from the surface soil in the field, and two cabinet temperatures of 20°C and 27°C. The maize variety and vigour were the same as for the field experiment. The experiment was designed as a complete randomised block.

The results showed that increases in soil moisture and temperature increased the rate of imbibition 36 hours after sowing, increased the speed of emergence and higher seedling emergence and growth of root and shoot. In consequence the rate of endosperm utilisation increased.

The results of the laboratory experiment also showed that PX610 has greater ability to emerge and grow, and higher speed of emergence than XL45 with similar results to the field experiment, but XL45 showed greater ability to imbibe water than PX610. The superiority of high vigour seed over low vigour seed in terms of emergence and early growth was also evident in PX610 but not in the variety XL45.

ACKNOWLEDGEMENT

I am indebted to my supervisor, Professor B.R. Watkin, for his wise counsel, suggestion of this experiment, and writing of this thesis. Without him this thesis would not have been completed.

I would particularly like to thank Dr M.J. Hill and Mrs E.M.H. Johnston for their patiently reading my manuscript and correcting my English for this thesis. Their advice and encouragement is much appreciated.

I wish to thank Messrs G.C. Arnold, N.S. Brown, Dr R.J. Clements and Mr R.S. Scott for their assistance with statistics and interest in the experiment.

I am grateful to Mrs N.M. Simpson for computerising half of the data in this thesis.

I would also like to thank Mr A.C.P. Chu for his suggestions and criticism in the discussion of this thesis.

Special thanks to Mr A.R. Khalip and friends for their voluntary help and encouragement throughout this study and to Mrs J.A. Jepson for doing a very good job of typing this thesis.

Thanks also to the staff of the Seed Testing Station for use of their facilities and technical assistance.

My grateful thanks also to Mr G. Wickham for his patience and encouragement during years of study.

I am also indebted to the New Zealand government for financial support and the opportunity to study in New Zealand.

## INTRODUCTION

Maximum yield is obtained from an optimum stand of any crop species. However there are many factors influencing the stand which can broadly be grouped as soil and plant factors.

Soil moisture, temperature and aeration influence germination. These factors plus soil structure influence emergence and establishment of seedlings.

Under field conditions, the factors mentioned are not always at optimum level which in turn influences the growth and final yield.

Any crop productivity depends also to a large extent on the quality of the seed planted. The quality of seed is known as "seed vigour" and is considered by some authorities to be the ability to germinate, emerge, grow and produce the final yield.

Normally each vigorous seed contains a strong miniature plant, but one should bear in mind that strength varies genetically. The miniature plant appears at rest but it is not (Moore 1963). Processes are at work and food is being used and energy released. As the processes continue the life of the miniature plant gradually weakens and slowly approaches the state of death. The processes in practice can be decreased or increased but not stopped. Therefore the extent of the resumption of this miniature plant (germinate, emerge and growth) depends largely on the vigour of seed and field conditions.

Mature seeds, carefully harvested, dried, processed, treated with a fungicide to control soil and seed borne organisms, and stored under optimum conditions should maintain high vigour. Pre-harvest conditions were found to have an influence on the vigour of seed (Flentje 1964), especially in temperate regions, e.g. New Zealand, whose rainfall is high and well distributed which is a problem during harvesting. However this problem also occurs in tropical regions like Thailand, but a common problem is poor storage conditions with high humidity and temperature.

As maize is currently becoming more important in New Zealand and is the second highest agricultural product following rice in Thailand, the present experiment was designed to study the vigour of maize seeds and seedling performance under field and laboratory conditions.

## 1. REVIEW OF LITERATURE

In order to provide a better understanding of the present experiment the literature review will consist of three parts.

The first part concerns the concept of seed vigour, and its significance. The second part is on seed germination which includes physical processes and changes occurring in the seed during germination. The last part of the review deals with the external factors affecting germination and emergence of seedlings.

The review is largely restricted to cereal with particular emphasis on *Zea mays*.

### 1.1 Seed Vigour

Heydecker (1969) stated that initially all seeds sold for sowing should be vigorous and therefore there should be no vigour problem. This is because the agricultural productivity depends to a large extent on the quality of the seeds which are planted. Then what is vigorous seed?

1.1.1 Concept of vigour - Heydecker (1965) described vigour as a man-made concept and can be made to mean what we choose it to mean. Therefore the opinion of 'vigour' seed differs greatly. In 1960 Delouche and Caldwell stated that "it is relatively easy to discuss what vigour is not, but much more difficult to elaborate a concept of sufficient scope to precisely define it". However the term vigour has become accepted by seed technologists through common usage. Isley (1957) pointed out that two views predominate in most concepts of vigour.

1. Susceptibility to unfavourable field conditions, and
2. Vigour per se as reflected in speed of germination and rapidity of growth rate of seedlings.

From the first concept vigour is a significant factor only under unfavourable field conditions. Differences in seed responses under favourable conditions are ignored and the fate of seeds low in vigour is death in the seed or young seedling stages and that vigour differences are of no importance beyond these stages. Even though this concept is rather limited it has a great appeal because the recognition of the importance of the environment in stand establishment is significant. Certainly difference in

vigour is most obvious under unfavourable conditions (Delouche and Caldwell 1960).

However the second view of the concept is somewhat inadequate because it does not sufficiently cover all the important areas of seed quality. On the positive side the vigour per se concept does place the emphasis on the seed where it belongs. This concept expresses physiologically and physically the conditions of the seed, seedling and beyond seedling stage. Moreover it applies to both favourable and unfavourable conditions. Numerous scientists have attempted to define seed vigour, all with particular bias and terminology. For example Isley (1958) defined vigour "as the sum total of all seed attributes which favour stand establishment under unfavourable conditions".

Schoorel (1960) states that "a seed is considered more or less vigorous depending on its ability to produce a normal plant under certain suboptimal conditions". Germ (1960) defined vigour as the "physiological power of seed" or the ability of seeds to produce seedlings capable of increasing in length and volume while still dependent on their own reserves. To Delouche and Caldwell (1960) seed vigour is "something" not adequately measured or reflected by the standard germination test.

Neeb (1970) as cited by Heydecker (1970) defines vigour as the totality of properties contributing to the defence against, and successful resistance to, biotic and abiotic hazards during germination under sub-optimal conditions.

Nutile (1964) defines vigour as the ability of the seed to produce vigorous seedlings as compared to the maximum vigour attainable for the species.

Woodstock (1969) described vigour as that condition of active good health and natural robustness in seeds which, upon planting, permits germination to proceed rapidly and to completion under a wide range of environmental conditions. Moore (1963) defined a vigorous seed as one that possesses maximum soundness for germination and seedling establishment under a wide range of expected planting conditions.

Heydecker (1969) in the review of "vigour in seed" said that all seed in a normally uniform consignment should keep well, should germinate

simultaneously and quickly without delaying, be free from seed borne disease; the seeds and seedlings should not be susceptible to microbial interference and be free from soil borne disease. The seedlings are strong enough to penetrate soil that is compact or covered by a hard crusted surface and are capable of establishing themselves in a wide range of environmental conditions. The seedlings should be capable of drawing their own reserves rapidly and building up metabolites and tissues while they are still growing on their own reserves. When they reach the autotrophic state this growth rate should be high and should be capable of rapidly filling the are allocated to them and of producing a high yield of the desired plant part within a short period of time.

In spite of these and many other attempts to define seed vigour there is still no agreement on an acceptable definition by the International Seed Testing Association. Therefore no agreement on a standard test for vigour has been accepted in the assessing of vigour.

1.1.2 The relationship between germination and field establishment - The International Seed Testing Association 1966 defines germination as emergence and development from the seed embryo of those essential structures which, for the kind of seed being tested, indicate the ability to develop into a normal plant under favourable conditions in soil. The purpose of seed testing is to gain information in respect to field planting value; however field conditions are often less than favourable.

Early workers such as Munn (1921, 1926), Whitcomb (1924), Milton (1925), Hay (1928), and Stahl (1931) found that field stands of several crops were commonly lower than germination results in the laboratory. These differences were especially great with seed of low viability. Munn (1921) compared 40 samples of corn and obtained 25% fewer plants in the field than in the laboratory. It was found that field stands were 20% lower in wheat, 15% for oats and 14% for barley (Munn, 1926). Porter *et al* (1938) found that the germination of cereal seeds was generally lower in the field than in the laboratory. However the rank of a given sample in the laboratory was generally maintained in the field. Sherf (1952) found laboratory seedlings to be 21%, 25% and 20% greater than field stands with water melon, Cantaloupe and cucumber respectively. However in 1953 he found that laboratory tests provided an accurate field condition for corn and soya bean.

Heydecker (1960) discussed the important factors in field



establishment and also considered that the laboratory germination test under optimum conditions still provides the most reliable estimate of probably emergence. But it needs to be supplemented by additional information on the behaviour of the seed under suboptimal conditions, because the seed lots difference in genetical characteristics or physiological conditions may have the same laboratory germination but show a range of field emergence under suboptimal conditions.

Essenburg and Schoorel (1962) as cited by MacKay (1972) concluded that there were generally very high correlations between laboratory germination and field emergence but, whereas in some species the emergence percentage usually shows a fairly constant relationship to the germination capacity, others are much more sensitive to differences in soil conditions. In maize, for example, the differences in pre-emergence mortality are associated with differences in the ability to germinate rapidly and to grow at low temperatures (Harper *et al*, 1955). Similar results were obtained by Matthews and Bradnock (1967, 1968) in peas. The mortality may be reduced, but not eliminated, by treating the seed with fungicidal dressing, and if necessary by supplementing the laboratory germination test with a special test to indicate susceptibility to pre-emergence failure (Matthews and Bradnock 1967, Harper and Landragin 1955).

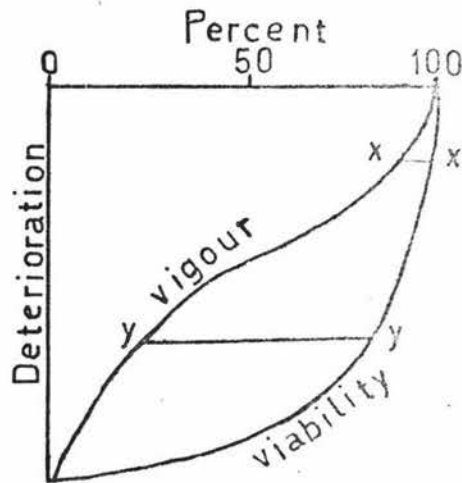
Stahl (1931) found a higher correlation between field establishment and the number of normal seedlings of cabbage and cauliflower after seven days than at the end of the test. Brett (1939) stated that the figure obtained half way through the test period was considered to represent the germination energy of the seed. Clark (1953) found the standard laboratory test was a reliable forecasting of the relative field germination of sweet corn under favourable conditions. However he stated that the cold test was a good forecasting of the relative field germination of sweet corn destined to be planted during the early part of the planting season when the soil temperature is still very low.

1.1.3 Relationship between viability and vigour - Moore (1972) stated that viability cannot be distinctly separated from vigour or embryo soundness. Loss of vigour or vitality commonly reveals different levels in the progress of the same deterioration processes.

Delouche and Caldwell (1960) had adapted the diagrammatic



representations of the relation between vigour and viability from Isley (1957) and Steinbauer (1958) which is shown in the following diagram:



The viability curve was drawn from data on ryegrass storage under warehouse conditions over a five-year period. The vigour curve is hypothetical but based upon several observations. The initial loss in vigour tends to parallel loss in viability, the vigour declines very rapidly, and finally the rate of loss shows as zero vigour or death of all seeds is approached. The importance of vigour is indicated by the points x and y which difference is greater than the difference of those points on the viability curve.

Loss of germination is clearly an important indication of loss of vigour but it is the last relevant indication, the first catastrophe (Heydecker 1972).

Many important detrimental changes take place before seeds lose their ability to germinate. Delouche (1969) listed the approximate sequence of deterioration as follows:

1. Degradation of cellular membranes and subsequent loss of control of permeability.
2. Impairment of energy-yielding and biosynthetic mechanisms, and consequently -
3. Reduced respiration and biosynthesis.
4. Slower germination and slower heterotrophic seedling growth.
5. Reduced storage potential.
6. Slower growth and development of the autotrophic plant.

7. Less uniformity in growth and development amongst plants in the population.
8. Increased susceptibility to environmental stresses.
9. Reduced stand - producing potential.
10. Increased percentage of morphologically abnormal seedlings and
11. Loss of germinability.

Caldwell (1956) found higher correlation of vigour test (under stress condition of high moisture) and field emergence than with the standard test in peas. Barnes (1960) as cited by Delouche and Caldwell (1960) found that presoaking in 5% Na.DH for 2 minutes or in water at 100°C for 5 minutes, and four days count were capable of detecting the vigour of seed lots better than the final count of standard germination as compared with the field emergence of wheat.

1.1.4 Causes of low vigour in seed - Each sound (vigorous) seed normally contains a strong miniature plant (embryo). It appears at rest but it is not. Processes are at work, food is broken down and energy released. By-products are being accumulated that sooner or later may tend to become toxic unless broken down completely or inactivated (Moore ). As degenerative processes continue the life of the embryo weakens (loss of vigour) and slowly approaches the state of death (loss of viability).

Heydecker (1969) listed a number of distinct causes for low vigour in seeds.

1. Genetic: Certain cultivars are more susceptible than others to adverse environmental conditions, and certain cultivars are less capable of growing rapidly than others (Pinnell 1951, Perry 1969, Haskell and Singleton 1949). On the other hand, the heterosis exhibited by hybrid cultivars results in resistance to adverse conditions, possibly as a result of their ability to grow rapidly, which itself may be due to some extent to the high efficiency of their mitochondrial metabolism - Rossman (1949), Haskell (1949), McDaniel (1969).
2. Physiological: "The physiological state" of seed can be suboptimal for two reasons: immaturity at harvest, Rush and Neal (1949), and deterioration during storage, Delouche (1968), Grabe (1963) found in corn. Dimmock (1947) noted reduced plant vigour in a number of corn lines associated with the use of immature seed and improper

drying.

There are some data which indicate that the environment in which seed is produced may have some effect on the performance of the subsequent crop (Riddell and Gries 1958; Stern 1960; Went 1959). Abdul-Baki (1969) listed the biochemical changes known to be associated with the reduction of vigour from the study of barley and wheat:

- (i) a decline in metabolic activities - reduced respiration, slower seedling growth, and lower germination.
- (ii) an increase in the total activity of certain enzymes by phytase, proteases, phosphatase.
- (iii) a decrease in the activity of respiratory enzymes, catalase, peroxidase, dehydrogenases etc.
- (iv) an increase in membrane permeability and resulting greater leakage of sugars, amino acid and inorganic solutes from the seed.

Cantrell et al (1972) found that in corn low quality seeds were more susceptible to injury of the respiratory system. He established a high positive correlation ( $r = +.930$ ) between 24 hours kernel respiration rate and seedling vigour, but a low correlation ( $r = +.270$ ) between root tip respiration rate of the young seedlings and seedling vigour. Lowell and Grabe (1967), Lowell and Feeley (1969) found that the respiration rates of seed during the first hours of germination are significantly correlated with subsequent seedling growth which provide a useful indication of seed vigour of corn. Similar results were obtained by Woodstock (1966), Woodstock and Grabe (1967) and Woodstock and Feeley (1965) in corn.

3. Morphological: Within a cultivar the smaller seeds often produce less vigorous seedlings than the larger seeds. Scaife and Jone (1970), Oelke et al (1969) showed that (lettuce and rice respectively) both size and density are important in determining vigour. Kittock and Law (1968) showed that bigger seed size (as weight of the seed) produces more vigorous seedlings in wheat. Abdullahi and Vanderly (1972) found that seed size significantly affected establishment and all vigour tests in sorghum.

Ovcharov (1962) reported differences in the biosynthetic activity of seedling from seeds of different weights in cotton and also showed

that position of the seed on the mother plant or even in the same inflorescence also affected these measurements, e.g. in maize. Within a cultivar large seeds have the advantage because the initial growth rate of their seedlings is higher, and if forced to continue to grow in the dark they are capable of growing to a larger size - McDaniel (1969).

4. Cytological: A number of workers have reported increased frequencies of chromosome aberration with an increase in the age of seed from a wide range of species, e.g. in onion (Nichols 1941, Sax and Sax 1964); in peas (D'Amato 1951), in Durum wheat and common wheat, barley, rye and peas (Gunthardt *et al* 1953) and in maize (Berjak 1968). Peto (1933) investigated seeds of maize and found that greater frequencies of visible chromosome aberration occurred in roots produced from old seed. It was supported by many workers already mentioned that chromosome damage in seed during storage is accelerated by the combined effect of temperature and moisture content and time.
5. Mechanical: The breakages of the creation of necroses which may spread through physiological mechanisms or through microbial activity. Tatum and Zuber (1943) showed in corn that injuries over the germ reduced seed vigour and stand in the field more than injuries over the other portions of the kernels when seed germinate at low temperature. Other investigators (Albert 1927; Brown 1920; Koelsler 1935) have suggested seed coat injury is an important factor in determining stand of crops. Seed of corn, wheat and rye (Moore 1972) frequently receive injuries on primary roots. Such injuries, however, are usually not considered as critical as similar injuries in sorghum. However minor injuries do tend to delay germination, reduce seedling vigour, encourage infection and hasten loss of viability.
6. Microbial: The infection of fungi and/or bacteria which accumulate on and in the seed during its maturation may endanger its performance under appropriate storage or field conditions, by causing heating in store, by direct attack, including the invasion and enlargement of microsis or by competition for oxygen.

1.1.5 Symptoms of lack of vigour - It is important to know and be able to recognise the symptoms causing lack or decrease of vigour. Heydecker (1969) listed a number of important ways lack of vigour can express itself:

- (i) Rapid deterioration during storage.
- (ii) Narrowing of the environmental conditions under which a seed will germinate.
- (iii) A longer time lag before all or some of the seeds show signs of germinating under a given set of germination-inducing conditions (reduced germination speed and/or uniformity).
- (iv) Greater susceptibility to colonisation by relatively mild micro-organisms.
- (v) Slow or abnormal growth of the resulting seedlings.
- (vi) Low yield.

## 1.2 Seed Germination

In the physiological sense "germination is the resumption of metabolic activity and growth by the seed tissues involving rehydration, utilisation of nutrient reserves and the gradual development of synthetic systems which enable the young plant to assume an autotrophic existence" (Street and Opik 1970).

In a strict botanical sense germination starts with imbibition, proceeds through the intermediate phase of enzyme activation and mitosis and ends with elongation of the radicle. As applied in Seed Testing this includes development by the embryo of the structures which are essential for growth into a normal seedling (Wellington 1966).

Mayer and Poljakoff Mayber (1963) define germination of seeds of higher plants as "that consecutive number of steps which cause a quiescent seed, with a low water content, to show a rise in its general metabolic activity and to initiate the formation of a seedling from the embryo".

Germination in the user's definition is the emergence of the aerial parts of the seedling from the soil.

Nearly all seeds contain some reserve nutrient. In maize and wheat for example endosperm is the nature of reserve tissue. The composition of the endosperm is carbohydrate 51-74% in maize and 60-75% in wheat; protein 10% in maize and 13% in wheat, and lipid 5% in maize and 2% in wheat (Wellington 1966). These chemical components are subsequently utilised during the process of germination.

Three distinct phases occur in the germination of seed (Toole 1956):

- (i) Imbibition of water.
- (ii) Cell elongation.
- (iii) Increase in cell numbers.

1.2.1 Imbibition - The first process which occurs during germination is the uptake of water by the seed - imbibition. Imbibition is a physical process which is related to the properties of seed colloids and is not related to the viability of seed as it occurs equally in live and dead seed (Mayer and Poljakoff Mayber 1963, Pollock 1972). This change in moisture content in the seed seems to be an essential factor in establishing the germinability of maize seed (Sprague 1936).

Although this initial uptake of water is a dominant factor in the indication of germination, its mode of entry and the sequence of events initiated by its entry are difficult to define (Crocker and Barton 1953; Keller et al 1970; Oota 1958; Opik and Simon 1963; Owen 1952; Toole et al 1956).

Pollock (1972) described three stages of water absorption by a dry seed as follows:

- (i) An initial period of rapid uptake.
- (ii) A lay period in which little water is absorbed.
- (iii) A second uptake state which is associated with embryo growth.

After the absorption of water all of the tissues of the seed become turgid. During the first 10 to 12 hours no elongation of cell walls and no chemical changes occur in maize seed germination (Toole et al 1956). Ingle et al (1964) found no changes in the reserve of the corn seed after 24 hours of imbibition.

Stile (1948) working with maize and cotton showed that the water absorption by the embryo is relatively much greater than that by the other part of the seed. The absorption is mainly due to be imbibition of protein (Mayer and Poljakoff Mayber 1963) which comprises about 13% of the grain (wheat, oats and maize) and is mainly in the embryo and aleuron layer as well as distributed throughout the endosperm (Wellington 1966). Other components like mucilages of various kinds, cellulose and pectic substances also contribute to swelling (Mayer and Poljakoff Mayber 1963). At the start of germination the initial uptake of water causes the entire seed to swell. Wheat grain for example may increase in volume by 22% after 5 hours and 42%



after 28 hours (Wellington 1966). In maize Ingle *et al* (1964) found that in the first 24 hours the water content of the seedling axis increased 131% while the scutellum increased 24%. By the fifth day over 50% water content of the seedling was held by the axis. Stiles (1948, 1949) believed that seed coats functioned as transporting organs for water from the exterior environment to the interior organs of the seed.

Studies relating to the entry of water into seeds have produced conflicting reports. (Collin 1918) studied water absorption by barley grains and concluded that there were localised areas at the germ side of the grain through which most of the water passed. The same general conclusion was reached by Harrington and Crocker (1923) in Johnson grass and Sudan grass. Davis and Porter (1936) noted that absorption and germination was more rapid when corn seeds were placed on wet blotters with the embryo side down than when the endosperm was in contact with the moist blotter. Shall (1920) however, believed that water entered generally over the entire surface of the seed coat. They stated that the embryo was a more efficient absorbing organ than the endosperm.

Several authors have reported on the effects of internal water stress on seed germination. Collis-George and Sand (1959, 1961, 1962) concluded that the water stress is not a decisive factor but instead it is the water transport that is critical to seed germination. This was studied also by Sedgley (1963) and Menohar and Heydecker (1964) who stressed the contact between the seed and its surroundings to be critical by affecting the water transport to the seed.

Peter (1920) reported that corn, peas, many beans and wheat generally had to reach moisture content (dry weight basis) of 46.4, 149.0, 108.3 and 69.1 percent respectively for germination. According to Swanson (1926) corn germinated when a seed moisture content of 33.4% was reached.

Hunter and Erickson (1952) found that the minimal amount of water that a seed must absorb for germination to occur varies depending on the species. In maize it is 30.5%, in rice 26.5%, in soya bean 50% and 31% in sugar beet.

The effect of temperature on imbibition is complex (Mayer and Poljakoff Mayber 1963) but imbibition generally proceeds more rapidly at higher temperature. The viscosity of water decreases with increased

temperature and its kinetic energy increases. Brown and Worley (1912) stated that the rate of water absorption by barley seeds was an exponential function of the temperature. Later work by Shull (1920, 1924) showed that temperature had much less influence on rate of moisture absorption than suggested by Brown and Worley.

Andrew (1952) found greater corn kernel volume changes occurring during a period of high temperature. He found that the lines that give low germination indices showed comparatively rapid and early increase in kernel volume, while lines with higher germination indices have less rapid changes in kernel volume.

Fayustov (1970) found water uptake was more intensive and reached a higher level in small than in large seed. Unripe dried seed absorbed water more intensively than fully ripe seeds. Increase in temperature intensified water uptake but did not affect its final level.

1.2.2 Cell elongation and increase in cell numbers - Toole (1924) found in Zea mays that the first change in germination after imbibition is all enlargement of the coleorhiza. Toole et al (1956) found that after 20 hours of imbibition elongation of the cell of the coleorhiza can be observed. In the next step, the coleorhiza breaks the pericarp and extends about 2 mm beyond the surface, then the radicle elongates to fill the coleorhiza.

Cell division is first observed in the root tip at about the time it breaks through the coleorhiza. Scutellum cells enlarge greatly without dividing and the nuclei become very prominent. Soon after the emergence of the coleorhiza the coleoptile and plumule push through the seed coat (Avery 1930).

Enzymes in the scutellum are active early in the germination process hydrolyzing maltose and soluble starch (Hagerman and Hanson 1955). With germination the mitochondria of the scutellum increase in number and migrate to the nearby endosperm where they are associated with corrosion of starch grains (Toole et al 1956). The reducing sugar (sucrose) as evidence of enzymatic change was first detected in the tip of coleorhiza and elongating radicle. It also happens in the mesocotyl as it elongates. Beside the reducing sugar soluble peptides also appear in the active region of the embryo (Toole 1924).

Toole et al (1956) summarised the onset of the germination



process after imbibition of water as involving increased enzyme activity in the region of the radicle and an increased respiratory rate, followed by elongation of the radicle.

1.2.3 Changes in storage products during germination - The chemical changes in the storage products consist of three main types (Mayer and Poljakoff Mayber 1963):

- (i) Breakdown of certain material in the seed.
- (ii) The transport of materials from one part of the seed to another (endosperm to embryo)
- (iii) The synthesis of new materials from the breakdown products.

Dry weight of the whole seedling falls during germination with a remarkable decrease in dry weight of endosperm. The decrease in the storage products in the endosperm and scutellum result in a proportional increase in the dry weight of the axis of maize seed (Ingle et al 1964). Cooper and MacDonald (1970) found that changes in weight of endosperm and scutellum in the light and dark were similar. The endosperm lost weight rapidly until 10 to 12 days at which time loss of weight was less rapid until the 16th day. After the 16th day, no further weight loss occurred. Root and shoot growth was highly correlated with endosperm weight loss through 12 days. The proportion of soluble compounds rose from 2% to 25% of the weight during the first 5 days of germination (Ingle et al 1964). A fraction of the soluble products is used in respiration and synthesis in the storage tissues themselves, but by far the greater part is transported to the growing parts (Street and Opik 1970).

The two major constituents of the endosperm are insoluble protein and carbohydrate which decrease with germination (Ingle et al 1964). The solubilisation of the protein begins during the initial phase of germination. However Ingle et al found no change in total nitrogen during the initial 4 to 24 hour period. They suggested that the hydrolysis and transport of this reserve material was not initiated by the end of the first day.

Duvick (1961) suggested that the accumulation of soluble protein in the endosperm during the first 3 days may be due to the release of zein from storage bodies which exist in the corn kernel. He found that insoluble protein in the endosperm decreased and this was paralleled by an increase of this fraction in the axis. During the first three days most of this

fraction appeared in the endosperm but in later stages of germination (4th and 5th days) the soluble protein content of the endosperm decreased while that of the axis increased at a rate parallel with its growth (Ingle et al 1964).

Similar to protein, carbohydrate hydrolysis was not initiated until after 23 hours of imbibition (Ingle et al 1964). The soluble carbohydrate content decreased initially in both endosperm and scutellum but increased in the axis from 2% at initial germination to 25% at the termination of the 5th day.

Fat (80% is contained in the scutellum) was progressively depleted over the germination period without increasing in other parts of the embryo (Ingle et al 1964). Beevers (1961) suggested that fat may be transformed to sugar or serve as respiratory substrate. This view is supported by Dure (1960) in corn and by Oaks and Beevers (1964), James and James (1940) in barley.

Amino acid in both endosperm and scutellum increased to a maximum around 3 to 4 days in maize (Ingle et al 1964) then dropped. The proportion of the total amino acid in the axis increased progressively with germination. The protein metabolisms of seedlings includes inter-conversions between amino acids. The amino acid composition of the storage proteins differs from that of the proteins of the growing embryo (Street and Opik 1970).

As soon as growth commences in the embryonic regions, the synthesis of nucleic acids, both RNA and DNA begins. Knowledge of the nucleic acid inter-conversions occurring during seed germination at present is limited (Street and Opik). Dry seeds have low nucleic acid contents but increase early in germination (Ingle et al 1964). This implies nucleic acid synthesis from non nucleic acid material. However the storage tissues do contain some nucleic acid, particularly RNA, and increases in the activity of ribonucleases in seed storage tissue have been reported. This suggests that breakdown products of storage tissue RNA may be used in RNA synthesis in the embryo (Street and Opik 1970).

1.2.4 Enzymes involved in hydrolysis of reserves - The first stage in the utilisation of nutrient reserves in hydrolysis is the results of activity by various enzymes. The enzymes are either present in the dry seed or very

rapidly become active as the seed imbibes water (Mayer and Poljakoff Mayber 1963). In cereals, an appreciable amount of amylase is present in ungerminated seed in an active form (Dure 1960). Enzymes involved in respiration are present in dry seed at quite high levels and need only hydration to become active.

- (i) Carbohydrate: Starch is normally broken down by amylase which has two forms  $\alpha$  and  $\beta$  amylase.  $\alpha$  amylase hydrolyses amylose and amylopectin which result in the production of dextrans from which maltose units are subsequently released by the action of amylase (Mayer Wellington 1966). This maltose is further broken down to glucose by maltase (Mayer and Poljakoff Mayber 1963). In maize Dure (1960) found that  $\alpha$  amylase originates in the scutellum and is secreted into the endosperm during germination which accounted for 9/10 of the total amylolytic activity found in endosperm at the peak of amylopectic activity (ten days after germination had begun). He also found that  $\beta$  amylase is in the endosperm of resting seed and accounts for only 1/10 of the total amylolytic activity.

Edelman et al (1959) showed that glucose is removed from the endosperm by the scutellum, converted to sucrose then transported to the embryo. Drennan and Bessie (1962) have suggested that synthesis of  $\alpha$  amylase in the cell of the endosperm is initiated by a stimulus from the germinating embryo. Paleg (1960, 1960) showed that the amylase activity increased in barley endosperm treated with gibberillic acid in the absence of the embryo. Overbeck (1968) studying the role of GA with barley concluded that the imbibition of water by the seed causes the embryo to produce a small amount of gibberillin. The GA then diffuses into the layer of aleurone cells that surround the endosperm causing them to form enzymes that in turn lead the endosperm to disintegrate and liquify. Cytokinin and auxin formed in this process then promote the growth of the embryo by making its cell divide and enlarge.

- (ii) Protein: Relatively little is known as to the exact nature of the mechanism by which proteins in the seeds are broken down. It may be assumed that protein is broken down by the action of proteases (Mayer and Poljakoff Mayber 1963). In cereal, e.g. maize, the major portion of protein is situated in the endosperm. The break

down of protein during germination with consequent rise in amino acid and amides is followed by protein synthesis in the growing part of the embryo (Ingle et al 1964). Recent research by Mikola and Kolehamainen (1972) with barley grain found two phases in the hydrolysis of reserve protein during germination. Firstly the reserve proteins in the cell of aleurone layer are hydrolysed to provide amino acids for an intensive synthesis of various hydrolytic enzymes, including proteinase. In the second phase these proteinases act on the bulk of the reserve protein stored in the endosperm. The hydrolysis products are absorbed by the scutellum and after some metabolic inter-conversion are transported to the seedling to provide amino acids for protein synthesis in the growing tissues.

- (iii) Lipids: Fats and oils are broken down in the first instance by the action of lipases to form fatty acid and glycerol. Normally neither of the breakdown products accumulate in the seeds (Mayer and Poljakoff Mayber 1963). Most of the stored lipid is converted to carbohydrate (Street and Opik 1970). From Oaks and Beever's (1964) demonstration of a functioning of glyoxylate cycle in the scutellum of 5-day old corn seedlings they indicated that part of storage fat of the seed may be converted to sugar which serves as respiratory substance. This agreed with the observations of Toole (1924) and Malholtra(1934).
- (iv) Nucleic acid: Various nucleases are involved in nucleic acid metabolism (Mayer and Poljakoff Mayber 1963). At the initiation of germination the content of nucleic acid in all parts of the seedling are low and increase in later stages of germination. Therefore it must be synthesised in the seedling (Ingle et al 1964).

1.2.5 Respiration of germinating seeds - Germination is an energy requiring process and is therefore dependent on the respiration of the seed. In the normal respiration process oxygen is absorbed, organic compounds disappear, carbon dioxide and water are given off and energy is produced. The process of respiration is called the oxidation process (Crocker and Barton 1953). The ratio of  $\text{CO}_2$  output to  $\text{O}_2$  consumption is called the respiratory quotient (RQ). The respiratory quotient is determined by the availability of respiratory substrate, e.g. carbohydrate and where the volume of  $\text{O}_2$  uptake is

equal to volume of  $\text{CO}_2$  given off the RQ is 1. For fat it is less than 1. RQ also varies with the stage of germination, and in different organs of the same seed (Mayer and Poljakoff Mayber 1963).

The intense metabolism of germinating seed is accompanied by a high rate of respiration per unit weight of tissue of the seed. It has been found that the rate of carbon dioxide output increases steadily from the start of water uptake, but there is a temporary lag in oxygen uptake until growth starts in barley (Oxley and Jones 1944).

In wheat (Levari 1960) as cited by Mayer and Poljakoff Mayber (1963) the  $\text{O}_2$  input and  $\text{CO}_2$  output rise is more or less uniform during the early stages of respiration. Although both oxygen input and  $\text{CO}_2$  output rise with time, they rise at different rates. As a result the RQ during early stages show very large variations. These point to very profound changes in the substrates used for respiration (Mayer and Poljakoff Mayber 1963).

Recently many workers have been trying to relate the rate of respiration of early hours in germination to seedling growth in order to use it as an indication of vigour in seed (Lowell and Grabe 1967). Lowell and Feeley (1969) found a positive correlation between the rate of  $\text{O}_2$  uptake during early hours of imbibition and the later stage of germination and seedling growth.

The enzymes used in respiration are catalases and oxidases (Crocker and Barton 1953). It was found that the respiratory enzymes are already present in the dry seeds, and hydration leads to a steep rise in respiration rate (Street and Opik 1970).

The main processes known to yield energy available in germination are Kreb's cycle (or Tricarboxylic acid cycle), glycolysis and pentose phosphate pathways (Mayer and Poljakoff Mayber 1963).

1.2.6 Speed of germination - Germination speed, rate, energy, or time taken by the seed to germinate can be expressed in many ways (Lang 1965).

- (i) As the proportion of seed germinating by a certain time after sowing (e.g. use of the first count or half way through germination).
- (ii) as the time needed to reach 25, 50 or 75% of the ultimate number germinating (Nichols and Heydecker 1968).
- (iii) as a special figure which takes into account the time taken by



each seed to germinate e.g. Kotowski's (1926) "Co-efficient of velocity" which expresses the mean germination of a sample by integrating the germination times of all individual seeds:

$$\text{c.v.} = \frac{n \cdot 100}{(n - D_n)}$$

Where  $n$  = number of seedlings germinated on  $D_n$ :  $D_n$  = number of days after sowing.

The basic conception of energy for measuring the speed of germination was originally based on a sound idea, the quicker the seeds germinate the better their quality.

Brett (1939) stated that the figures obtained half way through the test period were considered to represent the germination energy of seed. Heydecker (1962) pointed out that "germination energy" helps to offset the effects of changing environmental conditions. This concept was demolished by Verhey (1959, 1960). It was appreciated that seed samples differed in their rate of germination under test conditions, and might provide information about their relative vigour since a high seed respiration rate and high growth rate are likely to be linked by a high germination rate (Heydecker 1962).

Zaazaad (1949) as cited by Verhey (1960) stated that "as a rule quick germination is a strong indication of high viability". High energy points to high quality seed, but the reverse is not necessarily true. Windish (1942) stated that it is as important to determine the germination energy of barley as absolute germination capacity. In the observation of three typical malts with similar absolute germination capacities the maximum percentage of sprouts obtained in a 24 hour interval up to 120 hours (as germination energy) were 48.8, 95.2 and 70. This shows that large differences in "germination energy" are possible.

Throneberry and Smith (1955) established "vigour rating" which was equal to the number of normal seedlings per 100 seeds counted each day and multiplied by the reciprocal of the time in days. In corn, loss of viability appears to be closely associated with respiratory failure in most seeds, but variation in respiratory metabolisms did not explain the difference between germination percentage and cold test or vigour rating.

In 1962 Allan used Throneberry and Smith's method of vigour rating as "emergence rate index" and found a positive correlation with mature plant heights and coleoptile lengths of seedlings grown at 50°F and 90°F.

Maguire (1962) stated that the speed of germination is one of the oldest measurements of seedling vigour. The germination rate is calculated by dividing the number of normal seedlings per 100 seeds obtained at each counting in the standard germination test divided by the number of days seed has been planted. The value obtained at each count is then summed to obtain the "germination rate".

$$\text{Germination rate} = \frac{\text{No. of seedlings (normal)}}{\text{Days to first count}} + \dots + \frac{\text{No. of normal seedlings}}{\text{Days to final count}}$$

He stated that germination rate offers a simple method for evaluating seedling emergence and germination treatments. In his experiment with two varieties of Kentucky bluegrass, both with the same laboratory germination, he found they had different rates of total emergence as shown in the table below:

<u>Variety</u>	<u>Germination</u>		<u>Emergence</u>	
	Percentage	Rate	Percentage	Rate
Newport	87	4.1	37	0.6
PNW 205	87	5.5	42	1.3

The results show that seed lots may have the same germination capacity but differ in speed of germination which may be a good indication of the quality.

Derwyn *et al* (1966) and Smith (1968) reported that germination rate is important as a factor in establishment of annual grasses. However it is by no means universal. McWilliam *et al* (1970) stated that seedling vigour, involving the rate of extension of both root and shoot which is often correlated with germination rate is probably of equal or greater importance particularly with establishment in an arid environment.

### 1.3 The influence of environmental factors upon seed germination -

In order for a seed to germinate it must be placed in an environmental condition favourable to this process. Among the conditions required are an adequate supply of water, a suitable temperature and a suitable composition of gases in the ambient atmosphere, as well as light for certain seeds (Mayer and Poljakoff Mayer 1963).

The germination and emergence period is a critical one in the life of the plant. The fact that viable seeds are sometimes slow to germinate and emerge or fail completely when planted, and result in poor stands which in many cases reduce yield, and sometimes require resowing has been shown by Aldrick and Ieng (1969).

Primary environmental factors which influence germination are water, aeration, temperature, light, soil structure and micro-organisms.

The soil structure and micro-flora are constantly in a state of flux as a result of the changes in the temperature and in the oxygen and water supply. Temperature, water and oxygen supply change with time and these environmental conditions and changes can vary greatly from one locality in the soil to another. These changing and variable environmental conditions act on seeds whose modification from their original genetic potential differs according to the history of the individual seed (Pollock 1972).

1.3.1 Soil temperature - Most of the literature reveals that germination tests are carried out in moist blotters or sand and placed in germination cabinets at constant temperature.

Dubetz et al (1962) stated that from an agronomist's point of view it seems desirable that germination and emergence can be demonstrated by using accurate temperature control of a soil medium. Pollock (1972) concluded from observation of Edward (1934) on the germination of soy bean that "the major effect of temperature was not on the germination rate but on the time that germination began". For each temperature the curve of the cumulative germination against time shows a typical sigmoid curve. The curves are all similar but the point of origin changes with germination temperature. However it is difficult to describe in a meaningful way the effect of temperature on emergence.

Emergence is the summation of the effects of time and rate of germination plus growth of the seedling from radicle protrusion until the time of observation; temperature may affect each of these phases of growth independently.

Pollock (1972) used Edward, Pearl and Gould's (1934) data of the growth of cantaloupe seedling grown in the dark. The data showed that growth curves are sigmoid. Data of growth rates (cm/day) were plotted;



from the curve it showed that temperature controls both the maximum rate of growth and the time at which maximum growth occurs. The maximum total height and maximum growth rate occurs at the optimum temperature. Growth will not occur beyond minimum and maximum temperatures. Minimum optimum and maximum temperatures are referred to as the "cardinal" temperatures. The cardinal temperature is determined by source of the seeds, genetic differences even within a given species (Mayer and Poljakoff Mayber 1963). The concept of cardinal temperature is based on experiments performed at constant temperatures. However, seed germinating in field are exposed to diurnal temperature fluctuations. In laboratory such diurnal changes are known to be essential for certain species, e.g. in lettuce seed (Cohen 1958).

Leonard and Martin (1963) quote the following figures for a range of cereals:

Crop	<u>Temperature for Germination</u>		
	<u>Minimum</u>	<u>Maximum</u>	<u>Optimum</u>
Maize	40 - 50°F	-	86°F
Wheat	37 - 39°F	90°F	68 - 71°F
Ryecorn	33°F	85°F	55 - 65°F
Barley	37.4 - 39°F	82 - 86°F	68°F
Oats	36°F	-	-
Rice	70°F	108°F	85 - 86°F
Sorghum	45 - 50°F	-	80 - 85°F

An alternating day and night temperature produces optimum germination in some species, e.g. maize (18°C night, 25°C day) (ISTA 1966).

According to Aldrich and Leng (1969) the ideal soil temperature for maize growing is 75 to 85°F. At these temperatures the germination and rate of growth is best provided there is sufficient supply of water.

Aung et al (1968) studied soil temperature of the first two weeks after planting to predetermine the date of harvest in sweet corn. He found no correlation between soil temperature and date of maturity. However the soil temperature influenced the rate of germination and vegetative development. Pletser (1970) found a close correlation between seedling emergence of maize and soil temperature in the top two inches.

The effect of soil temperature on vegetative development was studied by Rybakova (1972). He found that maize sown under conditions of

high temperature utilised the reserves from the endosperm up to the second embryonic leaf stage, then the seedling depends on the absorption of nutrient by roots. Under conditions of low temperature maize plants continued to derive nourishment from the endosperm, together with utilisation of soil nutrient by the root up to the 5 and 6 leaf stage, about 40 - 45 days, depending on the soil temperature conditions.

Low temperature is found to be the problem in temperate areas where maize is planted. Low temperature ( $45^{\circ}$  -  $55^{\circ}$ F) retards the physiological activities of germinating maize and predisposes the seed and seedling to attack by various soil organisms (Hoppe 1953, Andrew 1953).

1.3.2 Soil moisture and aeration - The need for moisture during germination and emergence has long been recognised and the specific requirements of many species have been determined. Hunter and Erickson (1952) found that minimum seed moisture content for germination was approximately 30% for corn, 50% for soya bean and 31% for segmented sugar beet. They found that the maximum soil tension for germination was 12.5 atm for corn, 6.6 atm for soya bean and 3.5 atm for sugar beet.

The response of different seeds to increasing soil moisture tension (S.M.T.) varies but germination generally falls off as S.M.T. increases. Initial imbibition is not affected by temperature and oxygen supply but the germinative process is, and the uptake of water from this point onward interacts with these factors. Increasing S.M.T. causes an increase in the time of emergence (Read and Beaton 1959) as the following example shows in wheat:

Moisture tension (bars)	0.4	0.8	2.0	6.0	
Days to germinate	9.6	10.7	11.7	13.5	mean 11.0 days

Collis-George and Sands (1962) considered that the potential of water occurred in two components of importance in germination (1) matric (suction of capillary) potential and (2) osmotic (solute). They found that germination could be retarded as the matric potential decreased from that of free water.

It has been found that a decrease in soil moisture delays the emergence, and decreases emergence percentage in many crops (Ayers 1952, Hanks 1960, Parker et al 1965).

Parmar and Moore (1966) studied the effect of drought on

germination and seedling development of maize by using polyethylene glycol which simulated drought. They found that as osmotic pressure (o.p.) increased the percentage germination and subsequent seedling growth at 14 days decreased. The effect of high osmotic pressures were more adverse in the low than high quality seed lots.

From the results of Hank and Thorp's (1956, 1957) work it was found that the ultimate seedling emergence in wheat, grain sorghum and soy beans was approximately the same where the soil moisture content was maintained between field capacity and permanent wilting percentage if other factors were optimum for seedling emergence. However the rate of emergence was related directly to soil moisture content, which agrees with the work of Doneen and MacGillivray (1943) in many vegetable seeds.

1.3.3 Aeration - Most seeds germinate in atmosphere of air containing 20% oxygen and a low percentage, 0.03% carbondioxide. Seeds normally show lower germination is oxygen tension is decreased below that normally present in the atmosphere (Mayer and Poljakoff Mayber 1963). Under good aeration conditions the oxygen content of the soil atmosphere approaches that of atmospheric air.

Seedling emergence (germination and emergence) may be limited by insufficient oxygen diffusion at the seed depth. Hanks and Thorp (1956, 1957) found that wheat seedling emergence was limited whenever the oxygen diffusion rate as measured by the platinum micro-electrode method was less than about  $80 \times 10^8 / \text{cm}^2 / \text{min}$ . This limiting diffusion rate occurred at an air porosity of 16% in a silty clay loam, 17% in a silty loam and 25% in a fine sandy loam.

On the basis of limited oxygen diffusion rate, seedling emergence was limited by soil compaction or excess soil moisture. In practice a combination of these two factors more frequently occurs; when oxygen diffusion rate was limited germination did not occur (Russell 1952, Hanks and Thorp 1956).

Grable and Danielson (1965) found that, independent of aeration treatment used, germination growth of maize increased as soil moisture suction decreased until the soil was saturated. At that point, growth stopped, probably because of reduced oxygen diffusion rates. At lower soil moisture levels, reduction in oxygen concentration from 20 to 7.5% reduced root length by 20 - 30%.

Sensitivity to oxygen availability changes with stage of germination. Ikuma and Thimam (1964) found that during imbibition of lettuce seed oxygen is not required, but is required for radicle emergence. Unger and Danielson (1965) found that radicle emergence of maize occurred over a wide range of oxygen concentration 0 to cm Hg, but was reduced slightly at 0 and 150 cm Hg, 85% - 81% respectively. However, further root growth was sharply reduced by oxygen pressures below those of oxygen in the air.

The oxygen and carbondioxide percentage fluctuates in the soil due to (Russell 1952):

- (i) Changes in soil temperature
- (ii) Biological activity in the soil
- (iii) Moisture content of the soil
- (iv) Soil structure.

1.3.4 Soil structure - The influence of the physical condition of the soil on emergence of seedlings is commonly recognised, but not much work has been reported. Often the primary response of tillage is to reduce aggregate size. Aggregates must be small enough around seed and seedling root to prevent undue drying of the seed, to provide sufficient soil water - seed or soil water, and to provide adequate aeration. Yet aggregates should not be so finely divided as to encourage severe surface crusting when dry. Aggregation of soil particles and arrangement of the aggregates within the soil have a large influence on consistency and moisture relationship in the soil (Rossman and Cook 1967).

Johnson and Buchele (1961) found that as aggregate size increased over the rate 0.05 to 0.33 inch (1.25 mm to 1.75 mm) and compactive pressure decreased the rate of soil drying increased, and emergence of corn was less complete. In a field study on a clay soil in Ohio, the highest rate of corn emergence occurred when 30% of the soil passed through a 0.1 inch screen. Juggi and Gorantiuar (1972) found that germination of wheat seedlings was highest (100%) and fastest when sown in soil aggregates of 1 to 2 mm and lowest and slowest with aggregates of less than 0.5 mm (86%) and 5 - 8 mm (91%). Soil compaction of 1.1 gm/cc and 1.39 mm/cc gave the highest (96.6%) and lowest (89.6%) germination respectively.

Soil crusting can reduce seedling emergence (Hanks and Thorp 1956, 1957; Richards 1953; Taylor 1962). Even when seedlings rupture and

lift a small block of crusted soil ultimate stands are apparently reduced (Taylor 1962).

The formation of surface crust by heavy rain is a common occurrence, particularly on soils which have been intensively cultivated. Surface crusting has been considered to be due to depression of aggregates, then washing into and filling the pores in the immediate surface of the soil (Richard 1953).

Crust forms on soil of almost any texture except coarse sand with an extremely low silt and clay content. 17 - 19% of clay with a high percentage of medium to fine sands are more apt to form crusts (Lutz 1952, Limos and Lutz 1957).

The crust is, in effect, a condition in which aggregate structure of the soil surface is more or less destroyed. Crusting is a process whereby the particle arrangement of the soil changes towards the formation of a dispersed and compact condition. The degree of crusting depends on the intensity of slaking forces and specific characteristics of the soil material and their mode of arrangement and their reaction to the forces acting on them. Lawton and Browning (1948) found that high silt content is conducive to high strength on drying, perhaps because of weak aggregate bonding.

The direct disturbances to plant growth include the formation of a mechanical obstruction to the emergence of germinating seedlings and damage to their roots by the formation of warps and cracks in the drying crust.

Hanks and Thorp (1956, 1957) reported that crusts apparently limited emergence of wheat, grain sorghum and soy beans, especially at lower moisture contents. At a constant moisture content, seedling emergence decreased with increasing crust strength, although some seedlings emerged even when the crust was as high as 1400 milibars.

Stout and Stout (1956, 1961) found that surface pressures ranging from  $\frac{1}{2}$  to 5 psi have consistently induced better emergence than higher pressures.

Hanks (1960) found that soil moisture content is a very important factor considering seedling emergence in relation to crust strength. Seedling emergence will be limited where the soil dries because the crust



strength increases and the ability of seedlings to emerge at constant crust strength decreases.

Johnson and Buchele (1961) found that several sprouts were severely curled as a result of the attempt to emerge through the compacted soil layers. As the compacted soil dried out it offered a considerable resistance to seedling emergence. However Parker and Taylor (1965) found that small amounts of compression increased seedling emergence of sorghum seedlings but progressively decreased by increases in the strength above 3 bars and no emergence occurred in the strength greater than 18 bars. They also found that the rate of emergence was affected by soil strength, soil moisture tension and soil temperature.

However temperature affects the rate of emergence but not the relationship between soil strength and final emergence. Similar results obtained by Taylor, Parker and Roberson (1966) with Gramineae showed that emergence is affected only slightly as soil strength increases to about 6 to 9 bars, but none occurs above the range 12 to 16 bars.

Bulk density (B.D.) of crust is higher than the non-cruste<sup>d</sup> soil, total porosity is lower, microporosity is often higher, field capacity may be near saturation and mechanical strength in the dry state is greater (Hillel 1959, Black 1965). For this reason B.D. is often used as a measure of soil structure.

Hanks and Thorp (1956) found that B.D. was related indirectly to seedling emergence in that any change in B.D. changes other factors such as soil crust strength and oxygen diffusion rate. Poor aeration in a soil is likely to be caused by poor drainage in the soil which has a low pore space caused by compaction.

Top soil crusts are more dense than the soil underneath (Duley 1939, Lemos and Lutz 1957), and impedes gas movement to roots (Domby and Kohnke 1956).

Soil crusting depends on the intensity of slaking forces and specific characteristics of the soil materials and their mode of arrangement and their reaction of force activity on them (Lutz 1952). High silt content is conducive to high strength on drying (Limos et al 1957), perhaps because of weak aggregate bonding.

In the absence of a seal or crust, seedlings seem to emerge by

weaving their way through voids and by displacing or deforming some soil obstructions. Most seedlings can turn from excessive obstructions at acute angles and double back on themselves in large voids, but they cannot withdraw from small blind voids (Arndt 1965). When the opening is blocked, the stem tends to buckle in the direction of least resistance which is usually towards the surface. Emergence is often achieved in this way. Under crusted conditions, the resistance at the surface is such that buckling often proceeds in a horizontal direction with no emergence.

When a seal was present, the mechanics of seedling emergence were found to change with the following variables (Arndt 1965):

- (i) The water content of the seal, which changes rapidly and is not under control in dry land agriculture.
- (ii) The mechanical composition of the surface soil, which can vary widely with soil types and with depth and degree of soil inversion during land preparation operations.
- (iii) The size of seedling, which can vary widely with species. As the cross sectional area of the seedling stem increases, the flexibility of the stem decreases but the axial force that can be exerted for a given tissue pressure increases. Therefore, as the diameter of the seedling stem increases greater lifting power tends to compensate for loss of flexibility. Choice of crop varieties and grades of seed can influence emergence.
- (iv) The location of the seedling in the vertical plane, which can be predetermined by the depth of planting, but may be further affected by the subsequent movement of slaked soil.
- (v) The location of the seedling in the horizontal plane, particularly in relation to the position of the natural cracks in the seal.

1.3.5 Soil micro-organisms - The most complex of the environmental factors is the soil microflora. The importance is well illustrated by the germination of maize (Pollock 1972). Healthy corn seedlings normally are resistant to most parasite diseases under conditions that favour germination but in cold wet soil a germinating seed may be attacked by fungi that cause seed to decay and weaken or kill the seed or seedling (Hoppe 1953, Harper et al 1955).

Soil inhabiting fungi are the most common cause of seed rots and seedling diseases in corn. Among these are species of *Fusarium*, *Helmino-*

thosproium, Rhizoetonia, Trichoderma and Pythium (Hoppe 1953).

Trichoderma viride attack seed corn only at continuous temperatures exceeding 80°F (Hoppe 1953).

Harper et al (1955) showed very clearly in their experiment that pathogens which are active in injuring and killing maize grains and young seedlings during or after an exposure to low temperatures are primarily soil borne.

Ho and Melhus (1940) concluded that Pythium debaryanum was one of the earliest soil pathogens attacking seeds and root tips of maize seedlings and was the chief cause of seed decay or stunted growth.

Ho (1944) noted that for the pathogen of corn which he investigated, a low soil temperature combined with a high soil moisture is favourable for infection by these organisms.

The extent of damage differs markedly between soil samples taken from the same place at different times but not much from place to place (Harper et al 1955). The damage is shown to vary with soil moisture content. The mortality is greatest when the content of the soil is high (Harper et al 1954).

Inferior seed corn, due to immaturity, frost injury, old age, improper curing or storing or physical injury, is susceptible to attack by soil fungi (Hoppe 1953).

Tatum and Zuber (1943) found that pericarp injury is reflected in reduced germination under cold test conditions. There was a close relationship between pericarp injury over the germ and stand and yield in the field. The seriousness of a break is dependent upon how direct an opening it provided for pathogens to reach the embryo. These injuries showed no effect on germination under optimum conditions for germination. Treated seed with arasan gave better emergence than non-treated seed of comparable maturity (Rush and Neal 1949).