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

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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.

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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 vigourous 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 vigourous 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 vigourous 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 vigourous 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 suboptimal conditions.

Nutile (1964) defines vigour as the ability of the seed to produce vigourous 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 vigourous 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 defintiion 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.

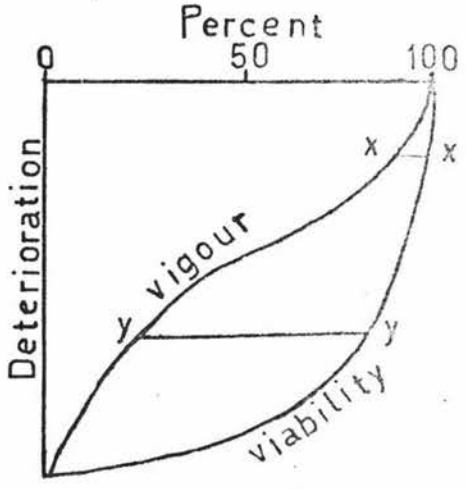
Essenburg and Schoorel (1962) as cited by MacKay (1972) concluded that there were generally very high correlations between laboratory germination and field emergence but, whereas in some species the emergence percentage usually shows a fairly constant relationship to the germination capacity, others 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 no 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 (vigourous) 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, phosphatease.

(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 andinorganic 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 vigourous 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 vigourous 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 infloresence 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 necrosses 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 condtions (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 stpes 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. Shull (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 hydrolying 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 sggested that the hydrolisation 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 iniated 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 interconversions 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) Carboydrate: Starch is normally broken down by amylase which has two forms α and β amylase. α amylase hydrolyses amylase and amylopectin which result in the production of dextrins 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 α 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 β 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 α 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 (Croker and Barton 1953). The ratio of CO_2 output to 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 O_2 uptake is

equal to volume of 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 carbondioxide 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 O_2 input and CO_2 output rise is more or less uniform during the early stages of respiration. Although both oxygen input and 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 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:

$$c.v. = \frac{n}{(n - Dn)} .100$$

Where n = number of seedlings germinated on Dn: Dn = 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).

Zaaizaad (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 metabolimsms 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".

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

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:

Variety	Germination		Emergence	
	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 Mayber 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 Leng (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 invdividual 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 sumation 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:

	Temperature for Germination		
Crop	Minimum	Maximum	Optimum
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° - 55°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 MacGillivary (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 x $10^{8}/cm^{2}/min$. 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 Thimann (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 constance 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 progessively 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-crusted 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 verticle 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, Rhizoctonia, 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 (Hope 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).

2. FIELD EXPERIMENT

The experiment carried out in the field to study the effect of the soil condition on the seedling emergence and the growth of the seedling up to 4 weeks after planting.

2.1 Material and Methods

2.1.1 Experimental site - The experiment was located in the Agronomy Department's experimental area at Massey University and on the soil classified as Tokomaru silt loam with a pH of 5.6.

The previous crops were white clover, red clover and lucerne grown side by side for 3 years.

2.1.2 Experimental layout - The layout of the trial was a randomised split split plot design with 4 replications. The treatments were:

(i) Three seedbed conditions: crusted, wet and control as the main plots.

(ii) Two varieties of maize, viz: PX610 and XL45 as sub plot.

(iii) Two levels of vigour: high and low as sub sub plot.

The experiment therefore included 12 treatments with 4 blocks, totalling 48 plots. The distance between the plots was 18 m by 2.7 m and were divided into 2 sub plots 9 m x 2.7 m for the 2 maize varieties randomly located. Each sub plot was divided again into 2 sub sub plots 9 m x 1.35 m for the 2 levels of vigour also randomly located.

Two guard rows were sown between each variety, one between each level of vigour within a variety, and two guard rows around the plot. A string grid was designed for each sub plot and was used to ensure correct placement. Placement was 75 cm between rows and 23 cm within the row.

A plan of the experimental layout is shown in figure 1.

2.1.3 Seedbed condition and sowing - The schedule of operation of soil preparation and other cultural treatments are shown in Appendix 1.

Figure 1 - Experimental Layout

A - Crusted plot

B - Wet plot

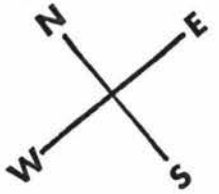
C - Control plot

1, 2, 3, 4 - Replication

PX610, XL45 - Varieties

H - High vigour

L - Low vigour



B_1	C_1	A_1	C_2	A_2	B_2	B_3	A_3	C_3	A_4	C_4	B_4
XL45 L	XL45 H	PX610 H	XL45 H	XL45 H	PX610 H	PX610 L	XL45 L	PX610 H	XL45 L	PX610 L	XL45 H
XL45 H	XL45 L	PX610 L	XL45 L	XL45 L	PX610 L	PX610 H	XL45 H	PX610 L	XL45 H	PX610 H	XL45 L
PX610 L	PX610 L	XL45 L	PX610 H	PX610 H	XL45 L	XL45 H	PX610 L	XL45 H	PX610 L	XL45 L	PX610 H
PX610 H	PX610 H	XL45 H	PX610 L	PX610 L	XL45 H	XL45 L	PX610 H	XL45 L	PX610 H	XL45 H	PX610 L

Figure 2: Operating the irrigation for the crusted plot.

Figure 3: Photograph showing the plots after sowing. The frames covered with polythene paper are over the crusted plots.

The area had been used previously for three plots of white clover, red clover and lucerne which had been growing for three years before the experiment started.

The crops were cut and the land was ploughed and rotary hoed over about 2½ months before sowing to let the plant material become decomposed. The plots were then marked out.

Two months before planting, ½ ton of lime was topdressed and harrowed in. Complete fertiliser 10:18:8 at the rate of 200 lb/acre was broadcast as a starter three days before planting.

Moisture at field capacity of the soil was determined soon after first ploughing. The method used was as described by Peters (1965).

For hard crusted plots, the land was repeatedly rotary hoed for 5 times prior to planting to destroy the soil structure.

After sowing, for hard crusted seed beds, water was applied by reciprocating pipe sprinkler (Figure 2). The pipes were set up 60 cm above the ground and the water spraying up about 2 m in the air. The application was under control all the time to make sure that the nearby plots did not get the water because of the wind blowing. Water was applied for 1 hour. After irrigation the plots were left to dry under transparent polythene paper to prevent any additional water during drying. The polythene paper was rested on 3 iron frames which covered each sub sub plot as shown in Figure 3. The frames were 45 cm high, 90 cm wide and 180 cm long. The plots were kept covered for 14 days.

For the control and the wet seedbeds after the first ploughing, the land was left undisturbed till three days prior to planting when the land was rotary hoed.

The soil moisture of the wet plots was kept at above field capacity at all times during the emergence period by soak hoses which were installed (18 m long) to cover the whole length of the plot.

One seed per drill was sown at a depth of 5 cm by hand planter. The seed was dusted with a mixture of 97% 50 W Captan and 3% DDT powder at the rate of 2 oz per bushel. The planting was completed in one day (6th November) with 2 planters.

A herbicide, Triazine, was applied at 4 lbs per acre to all

plots except the hard crusted plots as they were covered and there was no sign of weeds right through the experiment.

2.1.4 Maize varieties - The varieties used were PX610 and XL45. Both varieties are commonly grown in New Zealand, particularly in the North Island.

PX610 is a three-way hybrid of 115 days relative maturity (R.M.), shows some resistance to northern leaf blight and considerable resistance to lodging. This tall growing variety seems to be well suited to North Island growing conditions such as Gisborne and the Waikato. Constantly high yields have been recorded (personal communication).

XL45 is a single hybrid of 115 R.M. It shows high yield potential. The variety has been introduced to New Zealand recently.

The seed lots used were chosen from the reports on the Certificate of Analysis of the Seed Testing Station. All seed lots used were Government certified seed.

2.1.5 Maize vigour - The line of PX610 selected had 99.2% purity and 0.8% inert matter. The inert matter included a trace of mechanically damaged seeds. The interim germination (first count) showed 90% and final count 92%. This seed lot showing high interim count was designated as the high vigour line.

The low vigour line of PX610 of 99.5% pure seed and a trace of mechanically damaged seed showed an interim germination of 69% and a final count of 90%. Both seed lots were tested in August 1971. Prior to planting of the present experiment the seed was tested and found 79% and 58% interim with the final of 87% and 80% to the high and low vigour lots respectively.

The designated high vigour line of XL45 had 99.8% pure seed and 0.2% of inert matter with an interim germination count of 69% and final count of 76%.

The low vigour line of XL45 had 99.9% purity and a trace of broken seed. The interim germination was 56% and the final count 73%. This particular variety (XL45) of seed had very low germination which was assumed to be due to the bad pre-harvest conditions and poor handling, especially drying with high heat. Both seed lots were tested in July 1971.

2.1.6 Experimental methods -

(a) Seedling emergence - After daily observations were made and seedlings recorded till all seedlings emerged. Seedling emergence was expressed as the percentage of the total seeds sown. Recording began when the seedlings were able to be recognised which was about the eighth day.

(b) Measurement of harvested plants - Two harvestings were conducted at 2 and 4 weeks. At each harvest plants were randomly selected from each sub sub plot from one end of the row to the other.

(b1) Height of seedlings: 6 seedlings were randomly measured from ground level to the tip of the highest leaf.

(b2) Dry weight of the seedlings: 3 plants were randomly dug up in a square block. Two weeks old seedlings were dug in 8" x 8" square block and 12" x 12" at 4 weeks old seedlings. Soil was carefully taken off, the plants were put in plastic bags and labelled. The soil left on the roots was removed by washing and shoots were separated, labelled and placed in the oven at 80 - 85°C for 24 hours, then weighed. Dry matter of the shoot was expressed in gm per shoot. Root and shoot ratio was computed on the basis of dry matter.

(b3) Photosynthetic area: Fully expanded leaves were removed at the point of attachment to the leaf shoot and the area was measured by the automatic area meter model AAM-5, on the principle described by Murata and Hayashi (1967).

For the area of the photosynthetic leaf sheath, paper of the same area was used and the area was measured by the automatic area meter. The area was added to the leaf area.

Leaves not fully emerged were divided into that portion exposed to light and the portion not yet exposed to light. The exposed portion was measured for leaf area.

(c) Soil aggregate stability and bulk density - Four samples of soil were taken at random from every main plot. All the samples were air dried for 10 days in a well ventilated room. The expression of the results is in percentage of the weight of the soil left in each sieve to the total sample.

(c1) Wet aggregate: The wetting process usually causes considerable disruption of previously dry aggregate. Two samples of soil

from each plot were used. Air dried soil was sieved through $\frac{1}{4}$ inch square aperture screen to remove material other than soil such as pieces of plant material and stones. The soil was then hand shaken on a round hole 3mm sieve (Robinson 1955). The method and apparatus used for wet sieving was as described by Robinson (1955). The soil sample was divided by soil divider to get 30 gm soil. The time of wetting was 3 minutes. The remainder of soil on the 2mm size sieve was dried at 110°C for 18 hours then weighed. The results were expressed as weight in grams of oven dried soil remaining on 2 mm sieve per hundred gm of air dried soil (Robinson 1955).

(c2) Bulk density of the soil: It consists of drying and weighing of a known volume of soil. A core sample method was used, the diameter of the core being 1.75 cm and 9.45 cm long. The soil core was cut at the bottom end to leave only 5 cm of the top soil. The soil was then dried at 110°C for 18 hours and weighed. The volume of the soil was 24.06 cc. Bulk density expressed as gram of soil per volume = gm/cc.

2.1.7 Statistical method - Following the calculation of shoot dry weight per plant, leaf area per plant and root/shoot ratio from the average of three plants per pot and from six plants for the height, the following calculations were made.

For seedling emergence the arcsin transformation was required:
Arcsin transformation : $x = \arcsin x$

The arcsin values were obtained from Snedecor and Cochran (1967).

The data was analysed within harvests using analyses of variance for split split plot design.

The analysis of variance was constructed and carried out as outlined by Snedecor and Cochran (1967). The least significant difference for treatment comparison between various means were calculated according to formulae presented by Cochran and Cox (1957). The co-efficient of variation for describing the amount of variation in the experiment is outlined by Snedecor and Cochran (1967).

2.2 RESULTS

The results are divided into two parts. The first part is concerned with the field study involving seedbed conditions which includes soil moisture, temperature and bulk density and the second part with the results of seedling emergence and plant growth.

The following symbols apply in the graphs in both results sections:

NS no significant difference
\+ significant difference at 5% level
++ significant difference at 1% level

2.2.1 Seedbed conditions -

(a) Soil moisture, rainfall and soil temperatures - Soil moistures up to the depth of 5 cm are presented in Figure 4 a. Soil moisture was recorded six days after planting. On irrigated plots (wet seedbed) the moisture was kept above field capacity (18%) by irrigating daily except on the 10th day when natural rainfall was adequate. No further irrigation was applied after 13 days when the emergence of seedlings had ceased.

During the emergence period little rainfall was recorded (Figure 4). The moisture content of the crusted and control plots was low especially in the crusted plots during the first two weeks. Soil moisture rose sharply on the 18th day following the rain (13.1 mm) on the 17th day. Following the rain soil moisture levels were similar in all three treatments and showed a steady decline over the remaining experimental period.

Soil temperature at 5 cm depth during the emergence period was taken daily at 7 a.m., 10 a.m., 1 p.m., and 4 p.m. as shown in Figure 5, coupled with maximum and minimum temperatures. Soil temperature was recorded at 7 a.m. on the 3rd day after sowing and was above the minimum temperature for maize germination ($7^{\circ}C$). Generally the temperature of the wet plot was lower than that of the crusted and control plots. Temperatures recorded at 1 p.m. and 4 p.m. show very little difference in temperature in all soil conditions. Most days the maximum temperature was very high, above $25^{\circ}C$, which is suitable for maize seed germination.

(b) Soil aggregate stability - Highly significant difference between treatment of the soil left on the 2 mm sieve from wet sieving (Appendix 4). The differences are presented in Table 1.

FIG. 4 SOIL MOISTURE AND RAINFALL DURING EMERGENCE PERIOD

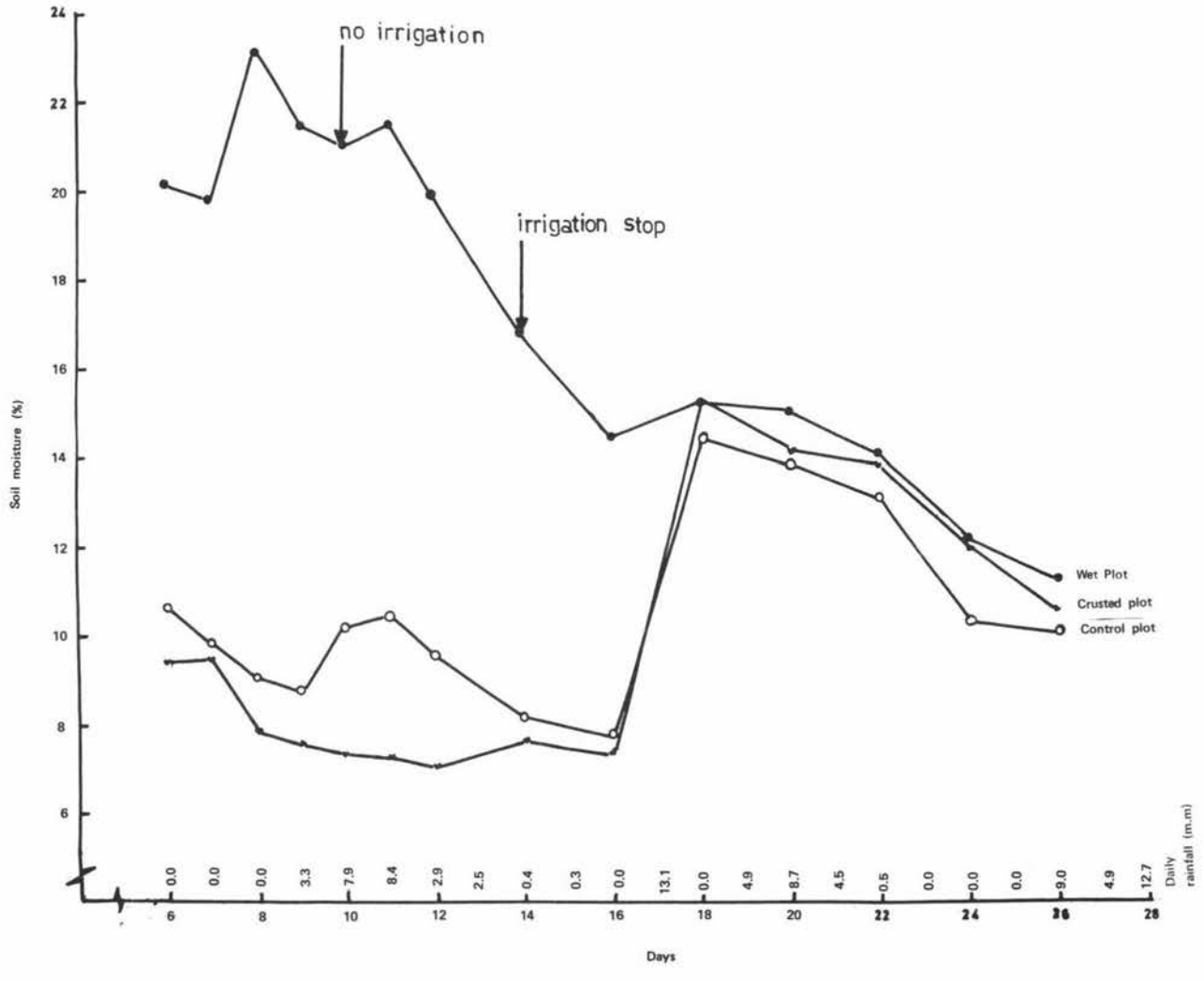


FIG. 5 SOIL TEMPERATURES RECORDED AT 7 a.m., 10 a.m., 1 p.m. and 4 p.m.

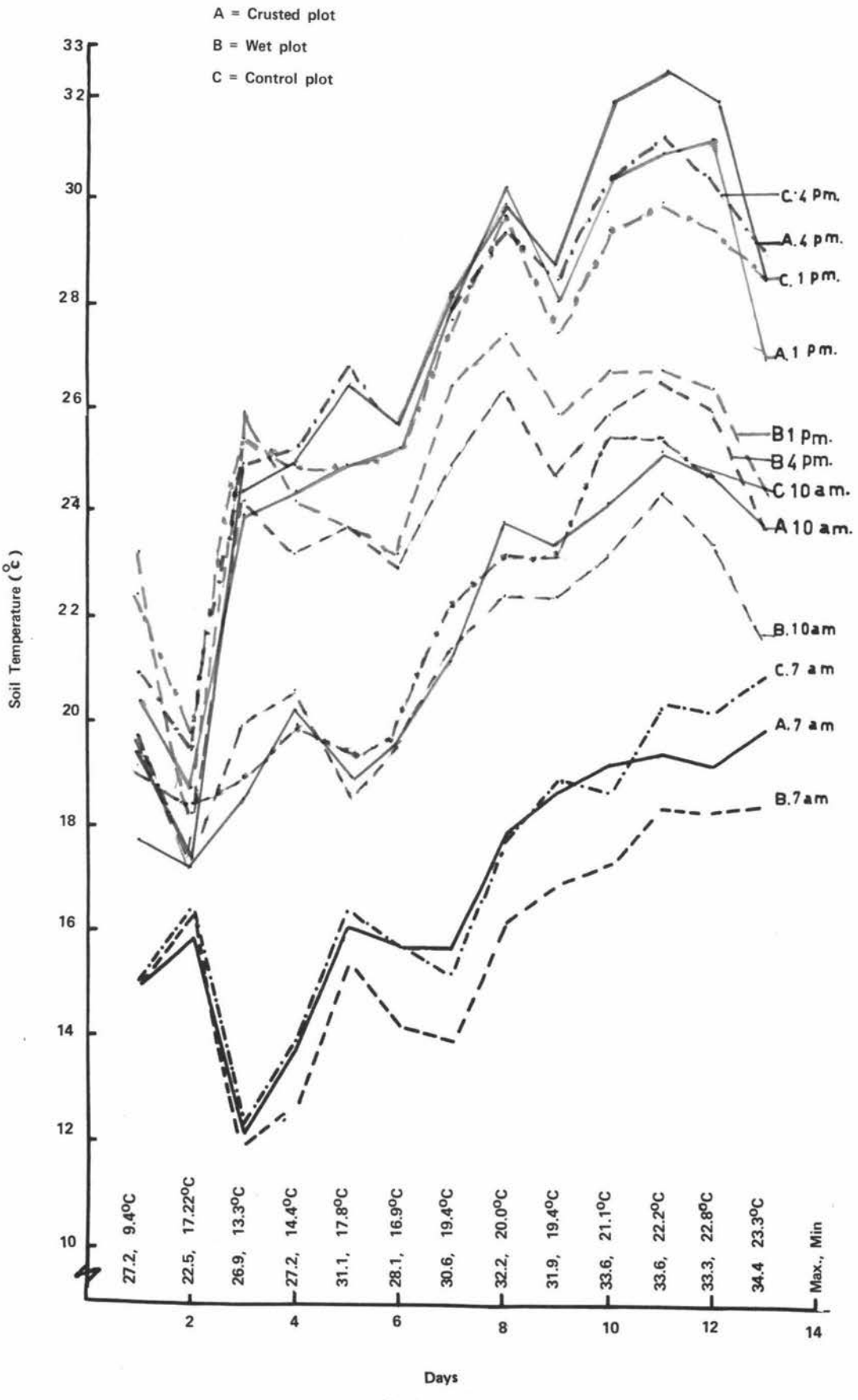


Table 1: Aggregate stability of different soil conditions.

Soil conditions	Aggregates (2 mm)		LSD 5%
Surface crusted	35.25+	(33%)++	
Below crusted	39.61	(41%)	5.94
Wet soil	28.66	(22%)	
Control	44.46	(49%)	

+ Arcsin figure

++ percentage figure equivalent to arcsin.

The soil from the control plots had the highest aggregate stability while that from the wet plots had the lowest aggregate stability. Soil from the crusted treatment showed an intermediate level.

(c) Bulk density of the soil (B.D.) - The B.D. of the crusted soil was significantly higher than that of the other treatments as shown in Table 2.

Table 2: Soil bulk densities.

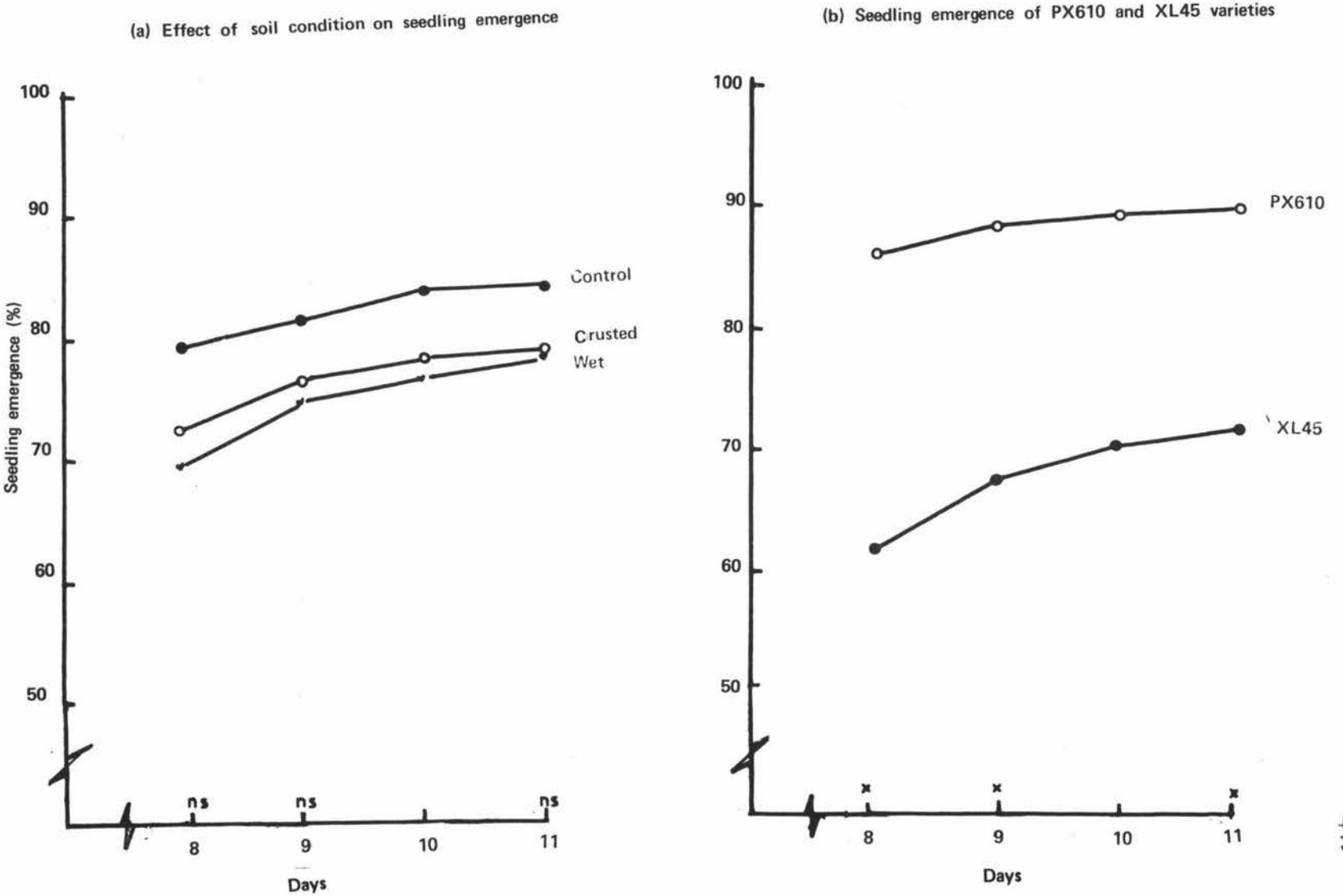
Seedbed condition	Bulk density (gm/cc)	LSD 5%
Crusted	1.80	
Wet plot	1.17	.13
Control plot	1.14	

There was no difference between the wet and control plots in B.D.

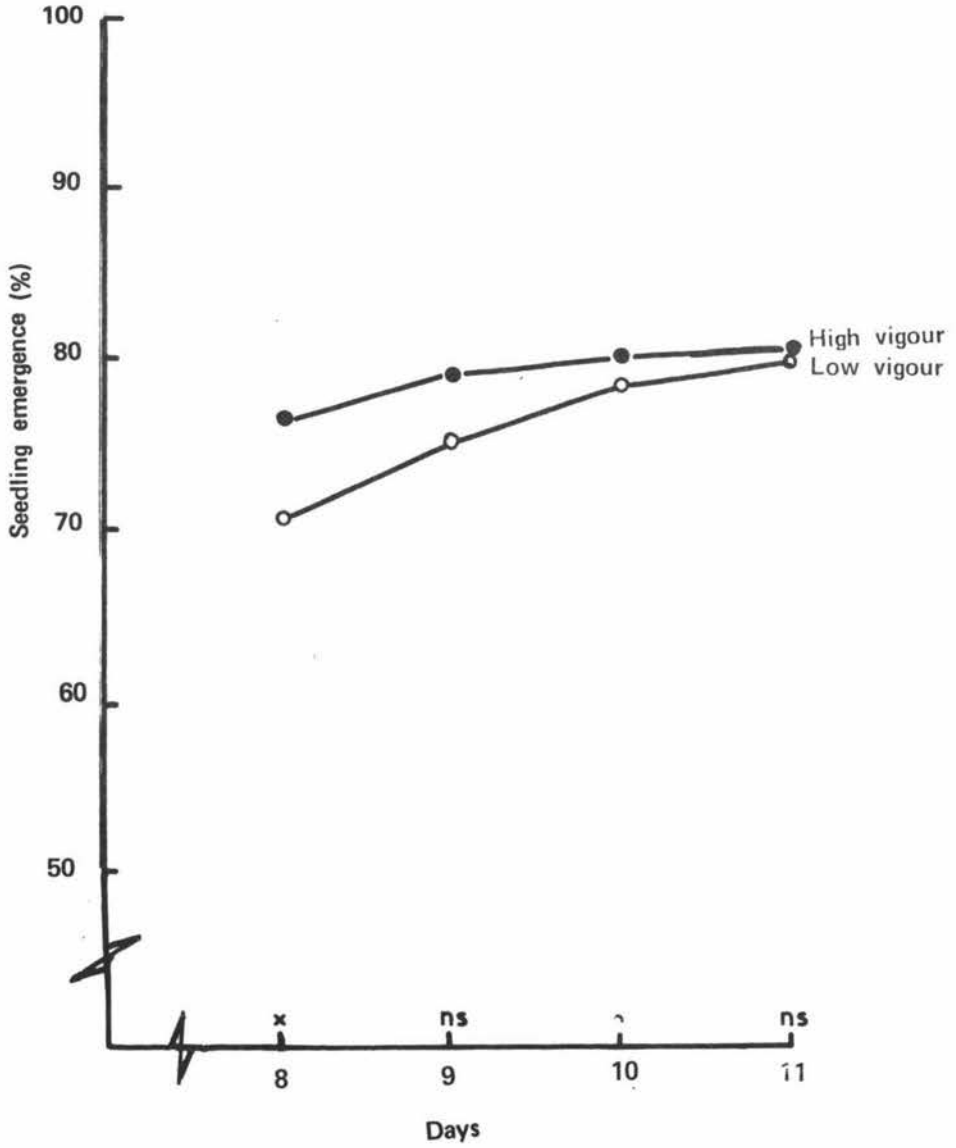
2.2.2 Seedling emergence and plant growth - In this section, the results of seedling emergence from day 8 to day 11 will be presented. Plant growth includes the height of seedlings, dry weight per plant, leaf area and root/shoot ratio of harvest at 2 and 4 weeks after planting.

(a) Seedling emergence - Emergence of seedlings was recorded from the date of planting which is shown in Appendix 6. The results show variability in emergence but the overall trends were for a considerable emergence on the 7th day from planting in most plots. Emergence of seedlings was completed within 11 days of planting.

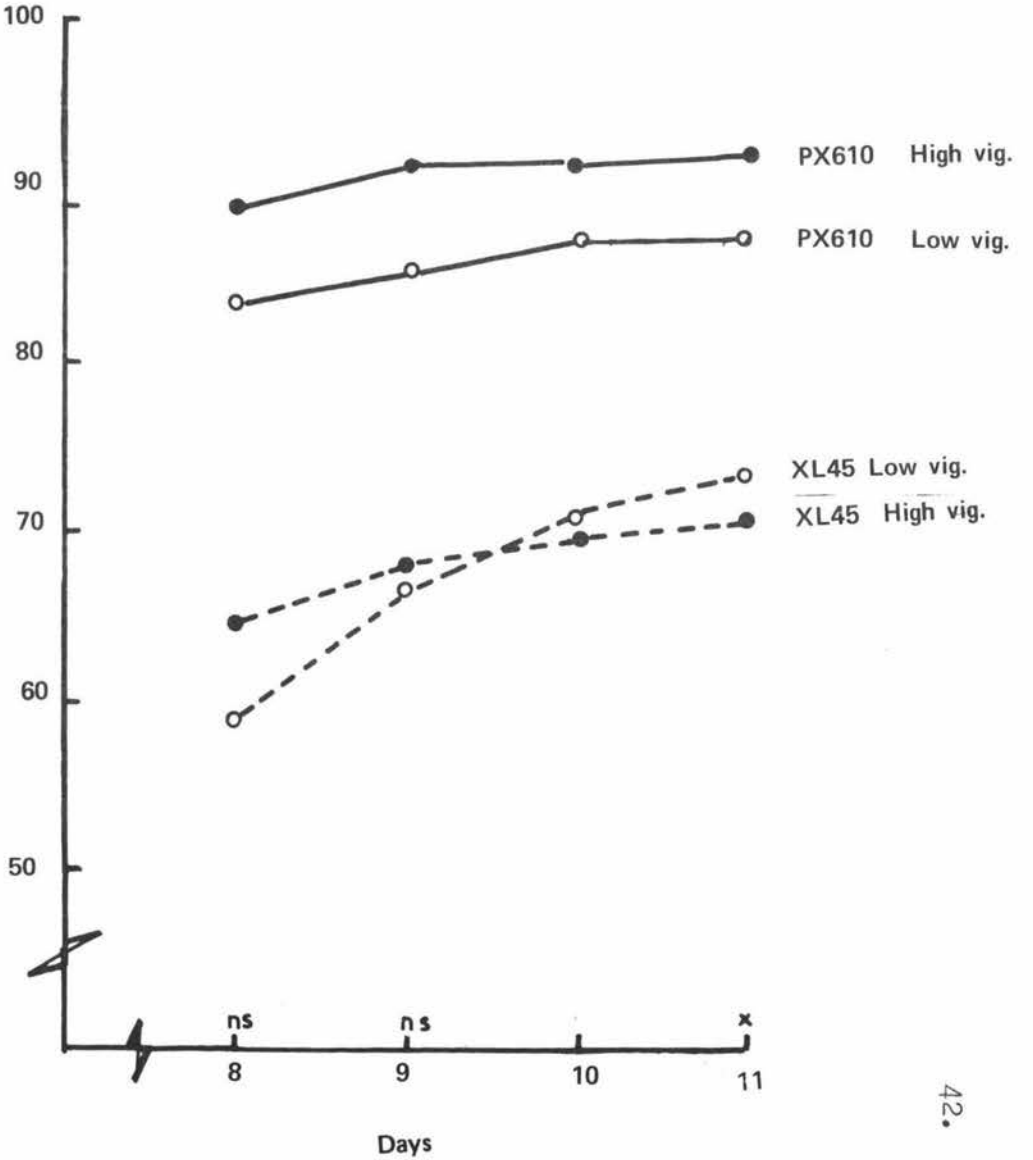
FIG. 6 SEEDLING EMERGENCE IN THE FIELD



(c) Effect of vigour on seedling emergence



(d) Effect of vigour levels of PX610 and XL45



Although not statistically significant seedling emergence appeared to be greater from the control treatment (Figure 6 a, Appendix 7).

The seedling emergence of the variety PX610 was considerably higher than from XL45, being 86.1% and 62% after 8 days. The emergence at the end of the emergence period was 89.5% and 71.8% for PX610 and XL45 respectively (Figure 6 b, Appendix 8). It was found in all soil conditions higher seedling emergence from PX610 than XL45 and in the control than in the crusted and wet plots.

A highly significant difference between the high and low vigour was found on the 8th day after planting only (Appendix 8, Figure 6 c). Even though high vigour seed had higher seedling emergence than the low, the difference after 8 days was no longer significant.

High vigour seed of both varieties tended to show a greater ability to emerge through the soil than lower vigour especially on the 8th and 9th day after planting, but the difference declined with time (Figure 6 d).

By the 11th day the high vigour line of PX610 showed significantly greater emergence than the low vigour line. The high and low vigour line of XL45 were not significantly different in this regard (Table 3).

Table 3: Seedling emergence of PX610 and XL45, high and low vigour.

Time (days)	Vigour	Variety				LSD^{+} 5%
		PX610		XL45		
8	High	71.8^{+}	(90%)$^{++}$	52.53	(63%)	NS
	Low	65.7	(83%)	51.9	(62%)	
	LSD^{++} 5%	NS				
9	High	73.61	(92%)	55.35	(68%)	NS
	Low	68.05	(68%)	55.02	(67%)	
	LSD^{++} 5%	NS				
11	High	74.51	(93%)	57.32	(71%)	5.04
	Low	69.19	(87%)	59.10	(74%)	
	LSD^{++} 5%	4.51				

LSD^{+} 5% for comparison between variety means at a given vigour.

LSD^{++} 5% for comparison between vigour means at a given variety.

\+ Arcsin value

++ an equivalent percentage to the arcsin value.

(b) Plant growth -

(i) Shoot dry weight - Highly significant effects of seedbed conditions and variety were shown on the first harvest at 2 weeks after planting for the soil condition effect and at both 2 and 4 weeks for the varietal effect (Table 4, Appendix 9).

Table 4 : Shoot dry weight at 2 and 4 weeks after planting.

Time (weeks)		Shoot dry matter (gm)					Means	LSD^{+} 5%
		Variety	PX610		XL45			
		Vigour	High	Low	High	Low		
2	Seedbed condition	Crusted	.28	.25	.18	.20	.23	.02
		Wet	.15	.17	.13	.14	.15	
		Control	.30	.30	.21	.22	.25	
	Means		.24	.24	.18	.18		NS
	Varietal Means		.24		.19			
	Vigour Means		.21		.22			NS
4	Seedbed condition	Crusted	2.25	1.82	1.38	1.67	1.78	NS
		Wet	1.56	1.80	1.86	1.49	1.70	
		Control	2.50	2.65	1.41	1.63	2.05	
	Means		2.11	1.06	1.55	1.59		NS
	Varietal Means		2.1		1.57			.25
	Vigour Means		1.83		1.84			NS

LSD^{+} 5% for comparison between the means of each treatment.

Higher shoot dry weight was obtained from seedlings grown in the control plot than hard crusted and wet plots. The average was 0.25, 0.15 and 0.23 grams for the control, wet and crusted plots respectively at 2 weeks after planting. The rank was maintained on the 2nd harvest 4 weeks after planting but the differences were not significant (Table 4).

Variety PX610 produced higher shoot dry weight than XL45 at both harvests. There was no difference in shoot dry weights between the low and high vigour seeds.

The interaction of maize variety and soil conditions at the 2nd harvest (4 weeks) is presented in Table 5 (Appendix 9).

Table 5: The effects of seedbed condition and variety on shoot dry weight.

Time (weeks)	Variety	Dry weight (gm) Seedbed condition			LSD^{+} 5%
		Crusted	Wet	Control	
2	PX610	.27	.16	.30	NS
	XL45	.19	.14	.22	
	LSD^{++} 5%	NS			
4	PX610	2.04	1.68	2.58	.46
	XL45	1.53	1.68	1.52	
	LSD^{++} 5%	.58			

LSD^{+} 5% for the comparisons between seedbed conditions within a variety.
LSD^{++} 5% for the comparisons between varieties within a seedbed condition.

After four weeks the control plants of PX610 had higher dry weight than those of the crusted and particularly the wet treatment. Plants of XL45, however, showed little difference between treatments.

(ii) Leaf area per plant - Highly significant effects of seedbed conditions and variety were revealed in the analysis of variance at 2 weeks after planting as shown in Table 6 (Appendix 10).

Table 6: The leaf area per plant at 2 and 4 weeks after planting.

Time (weeks)	Leaf area $(cm)^2$			LSD 5%
	Soil condition			
	Crusted	Wet	Control	
2	77.51	64.88	82.34	13.50
4	369.97	314.05	357.59	NS
	Variety			
	PX610	XL45		
2	82.53	67.28		9.85
4	379.45	313.65		11.31
	Vigour			
	High	Low		
2	72.91	76.91		NS
4	339.03	354.06		NS

The leaf area per plant was highest from seedlings grown in the control plot and lowest from the wet plot at the first harvest two weeks after planting. By 4 weeks the leaf area per plant was still relatively low in the wet treatment with the other two treatments maintaining a higher but similar leaf area/plant. Higher leaf area was produced by variety PX610 than XL45. There was no significant effect of vigour on leaf area per plant even though the low vigour seedlings showed higher leaf area production than the high vigour seedlings.

(iii) Seedling height - The results on the height of seedlings are shown in Table 7 (Appendix 11).

Table 7: Height of seedlings (cm) at 2 weeks and 4 weeks after planting.

Time (weeks)	Soil condition			LSD 5%
	Crusted	Wet	Control	
2	19.29	14.10	17.75	2.9
4	39.34	37.78	37.73	NS
	Variety			
	PX610		XL45	
2	18.5		15.65	2.09
4	41.76		34.63	2.04
	Vigour			
	High		Low	
2	16.85		17.26	NS
4	38.57		37.82	NS

Highly significant variety effects were revealed at both harvests with PX610 plants being taller than XL45 plants. A significant soil condition effect was also found at the 1st harvest with the plants from the wet plot being shorter than those in the crusted and control plots. Seed vigour had no significant effect on plant height.

(iv) Root to shoot ratio - Highly significant effects of seedbed condition and significant difference between varieties at 5% are shown in Table 8 (Appendix 12).

Table 8: Root to shoot ratio at 2 and 4 weeks after planting.

Time (weeks)			Root/shoot ratio				Means	LSD 5%
		Variety	PX610		XL45			
		Vigour	High	Low	High	Low		
2	Seedbed condition	Crusted	.71	.72	.68	.74	.71	.072
		Wet	.62	.66	.58	.76	.65	
		Control	.74	.72	.89	.96	.82	
		Means	.69	.70	.72	.81	.74	NS
	Varietal Means		.70		.77			.06
	Vigour Means		.71		.76			NS
4	Seedbed condition	Crusted	.43	.43	.46	.44	.44	.05
		Wet	.33	.36	.35	.35	.34	
		Control	.34	.27	.38	.46	.37	
		Means	.37	.35	.40	.41	.39	NS
	Varietal Means		.36		.41			.03
	Vigour Means		.39		.39			NS

The root/shoot (R/S) ratio was lower at 4 weeks than 2 weeks after planting. R/S ratio was highest in the control and lowest in the wet treatment 2 weeks after planting. After 4 weeks the R/S ratio was highest in the crusted treatment with the wet and control treatments showing no significant difference.

Plants of XL45 had significantly higher R/S ratio than PX610. Once again seed vigour had no significant effect on R/S ratio of the respective lines.

The significant interaction effect of seedbed conditions and variety was found at 4 weeks after planting (Table 9) and shows that the R/S ratio of XL45 plants compared with PX610 plants were only significantly greater in the control treatment.

Table 9: The effect of seedbed conditions and varieties on root/shoot ratio.

Time (weeks)	Seedbed condition	Root/shoot ratio		$LSD^{+}5\%$
		Variety		
		PX610	XL45	
2	Crusted	.72	.71	NS
	Wet	.64	.67	
	Control	.73	.93	
	LSD^{++} 5%	NS		
4	Crusted	.43	.45	.057
	Wet	.35	.35	
	Control	.31	.42	
	LSD^{++} 5%	.058		

LSD^{+} 5% for comparisons between seedbed conditions and given variety.
LSD^{++} 5% for comparisons between varieties at a given seedbed condition.

2.3 DISCUSSION

The results will be discussed in the order of soil condition, variety and vigour affecting seedling emergence and growth under field conditions.

2.3.1 Soil conditions -

(a) Effect of soil condition on seedling emergence - Emergence of seedlings was started evenly in the crusted soil plots (2.2.2.a). On the control soil plots emergence was variable (6 - 7 days) and varied from 6 - 8 days on the wet soil plots.

Though there was no significant effect of soil conditions on seedling emergence, slightly higher seedlings emerged from the control soil at all dates tested (Figure 6 a). The differences may be real, biologically, but not statistically because of variation of the conditions created.

Even though seedling emergence in some plots was observed on 6 - 7 days after sowing, no recording was made until the 8th day because of the difficulty in recognising the tiny pale yellowish coloured seedlings, especially in the control and wet soil plots. It was also much easier to observe the first appearance of seedlings on the crusted plots than the others, which may have caused some degree of error of observation in the control and wet soil plots.

This lack of significant treatment difference recorded is not in agreement with previous workers (Hank and Thorp 1956, 1957; Richards 1953; Taylor 1962; and Carnes 1934) who found surface crusting caused a reduction in seedling emergence of many kinds of crops. Possibly the crust created in the present experiment was not thick enough, as shown by the large number of surface cracks that were formed. Nevertheless, it is also possible that the soil type used had no crusting problem towards the emergence of maize seedlings. From the observation the crust was easily penetrated by the tip of maize seedlings which resulted from the crust being loosely bound. This may have been because the surface watering applied was not severe enough, even though the crusted soil had a very high bulk density (B.D.) (Table. 2). Adams et al (1960), and Smith and Cook (1945) found that as the surface soil density (B.D.) rose as a result of compaction (mechanically) the rate of seedling emergence of a number of species including corn was reduced and population decreased. Similar results were obtained by Dasberg, Hillel and Arnon (1966) that preplanting

compaction reduced seedling emergence of sorghum.

It is important to note that the results show that under optimum conditions (of the control plot) the final population reached the level of total germination test previously attained in tests at the Seed Testing Station, which is in agreement with Stahl (1931), Clark (1953), and Abdulla and Roberts (1969).

Wet soil conditions again did not greatly affect seedling emergence. The sole effect was to delay emergence in some plots. This may have been due to variations in soil moisture itself despite the fact that soil temperatures were considered satisfactory for germination and emergence. Wet seedbed was found to be dangerous for seedling establishment in some vegetable seeds (Ophanose and Heydecker 1967). This effect will vary in different species and also differ in degree as shown by Arnt (1965).

(b) Effect of soil condition on plant growth - Even though seedling emergence of maize was not affected by soil conditions, there was a definite effect on seedling growth especially at the first harvest taken two weeks after planting. However the effect had disappeared by the second harvest, i.e. after 4 weeks.

Two weeks after planting there was a remarkable reduction of growth particularly in relation to leaf area per plant, shoot dry matter, R/S ratio and height of seedlings grown in the wet treatments compared with the crusted and control soils. It is possible that under wet soil conditions problems arose due to lack of aeration (Boynton and Renther 1938, Lawton 1945) which inhibited root activity and growth which has been recognised for a long time (Clements 1921).

An indirect effect of the excessive soil moisture may be on the supply of nutrients to the plant (Oskamp and Batjet 1932, Lawton 1945, Hoffer 1945).

Slightly lower soil temperature recorded under wet conditions may have also affected seedling growth (Figure 5). For example a reduction on the absorption of water by the root was found by Nelson (1944), Kramer (1942), Bailey & Jones (1944), and nutrients Hongland and Broyer (1936) and Brown (1939) at lower temperature.

Growth of seedling in the control condition was greater than

in crusted soils as shown by the higher shoot dry weight, leaf area and higher R/S ratio recorded. This may have been caused by lower soil moisture levels during the 2 weeks period after planting or after emerging in the crusted treatment (Figure 4). Morton and Watson (1948) found that greater leaf area production in sugarbeet resulted from higher soil moisture.

Observations indicated that seedling root development in the three soil conditions was different. This was shown by greater branching of the roots and root hair development in the crusted soil treatment compared with the control soil. Both treatments produced seedlings with more strongly developed root systems than in the wet soil. Under these wet conditions roots were quite thick and short with very few branches from the secondary root, which may have been caused by lack of aeration as previously found by Lochring (1937), Weaver & Himmel (1930), and Troughton (1972). R/S ratio of the seedling was also lowest in the wet soil treatment, and supports the work of Penfound (1931) and Smith (194) who showed that as soil water level increased the R/S ratio decreased.

The effect of soil condition on plant growth had generally disappeared at the second harvest (4 weeks after planting) and suggested that there may have been an improvement in soil air conditions as the experiment progressed. However the effect on R/S ratio was still present, the R/S ratio being lower in the crusted and wet soil treatments.

The increased plant growth occurring in a large number of species following improvement of aeration has been observed by many workers for the past 60 years, e.g. Arrington and Shive (1936), Gilbert and Shive (1942, 1945), Hall and Underwood (1914), Shive (1941), Stewart Street (1947), and Troughton (1972).

Results showing the increase in coefficients of variation of leaf area per plant, shoot dry weight and R/S ratio between the 2nd and 4th week after sowing are given in Appendices 9, 10 and 12. Such variation may have been caused by:

1. variation of the soil moisture condition in the soil,
2. varying degrees of competition after some plants had been removed at the first sampling.

Although other workers (Phillips and Kirkham 1962, Adams et al 1960, Adrich and Leng 1969) have recorded significant effects of such soil conditions on final yield of maize, it is suggested that such would

not have occurred in this experiment.

2.3.2 Effect of variety - A great difference between varieties was shown in both seedling emergence and plant growth.

Seedling emergence was greater and possibly faster in PX610 than XL45 (Figure 6 b). At the first recording 8 days after planting higher emergence percentage was measured from PX610 than XL45 (87% and 67% respectively).

It was found that both varieties had greater ability to emerge under the conditions in the control treatment than in crusted or wet soils. Under the conditions of the control plot the final figure for both varieties reached in a laboratory germination test was slightly lower than field germination percentages in both the crusted and wet soils. These results agree with previous work of Matthews and Bradnock (1967, 1968) and Perry (1970) in peas. Nevertheless Heydecker (1960) maintains that under optimum conditions the germination test still provides the most reliable estimate of emergence.

The emergence of seedlings in the field followed the order of germination in the laboratory as PX610 was higher than XL45. This finding agrees with previous workers (May 1926, Mackay 1972, Mackay and Tonkins 1965, Milton 1925, Munn 1921, 1926; Stahl 1931, and Whitecomb 1924) that percentage emergence was in the order of laboratory germination.

PX610 produced greater leaf area (Table 6), shoot dry weight (Table 4) and height over XL45 but XL45 produced a higher R/S ratio in both samplings (Table 8). With shoot dry weight and leaf area, PX610 produced about 20% higher than XL45. This shows that both seedling emergence and seedling growth rate were also greater in the former variety.

The seedlings of both varieties at 4 weeks produced equal shoot dry weight (Table 4) and R/S ratio when grown in wet soil (Table 9). PX610 had a higher shoot dry weight than XL45 at 2nd week, but XL45 had greater R/S ratio. The results also indicated that PX610 is more sensitive to prolonged wet conditions, as XL45 recovered from the effects of wet conditions by reaching a similar dry matter production to PX610 in 4 weeks in all soil treatments (Table 5).

2.3.3 Effect of seed vigour - The distinction of high and low vigour described in this experiment was based on the interim count of the laboratory

test for germination. The laboratory germination test results show higher germination in PX610 than XL45 (91% and 71% respectively) with interim of 75% and 62%. This difference suggests that PX610 has greater vigour than XL45. This may also infer genetic differences which through an effect of seed vigour may in turn influence seedling emergence and growth.

The possible cause of low vigour in XL45 may have been damage due to poor pre harvest conditions, which resulted in harvesting being delayed. The importance of environmental factors acting on seeds before harvest or indirectly on them through the parent plant and affecting their viability has been realised (Swanson 1946, Skazkin and Khvan 1962, Salter and Goode 1967, and Scott 1969). For example rainfall prior to harvest has been reported to have deleterious effects on germination and vigour of peas (Flentje 1964). In addition poor harvesting conditions and poor handling after harvesting of high moisture seeds may reduce seed vigour as found by Perry (1964), Perry and Harrison (1970)in peas, Rampton and Lee (1969) in Dactylis glomerata, and Khan and Laude (1969) in barley.

Nevertheless in spite on these comments it was found that emergence under field conditions was not affected by seed vigour in terms of the final emergence (Figure 6c). This finding disagrees with the results of many workers such as Grabe (1964), Matthews and Bradnock (1968), Heydecker (1960, 1962, 1966), Clark (1953), Fritze (1965). These workers used entirely different criteria in describing high and low vigour.

However the early results did reflect some agreement with the above workers as high vigour seeds did show faster seedling emergence than low vigour seeds as indicated by higher percentage emergence recorded on the 8th day (76% and 70% in the high and low vigour lines respectively) (Figure 6 c).

As for growth of seedlings, no effect of vigour was found. Possibly the criteria used in defining vigour were not sufficiently critical. In addition it may be that the percentage differences obtained at the different vigour levels were not great enough. Particularly in XL45 there was no difference in emergence of seedlings of both high and low vigour. Generally the high vigour of PX610 was shown superior than the low vigour seeds (Figure 6 d). The final emergence of high and low vigour seeds of PX610 was 93% and 87% respectively and for XL45 71% and 73% respectively.

Although the adverse effect of weak seed in reducing field stands with a subsequent reduction in yield is well known, the reports on the effect of weak seed on field performance of the plant growth from them are contradictory. Delouche and Caldwell (1960) stated that "the literature contains very little data none of which is very conclusive showing that vigour differences affect yield".

For example Kiesselbach (1937) found that well matured, viable corn seed up to 4 years old was satisfactory in field performance. However Dangan and Koehler (1944) observed that hand processed seed over 4 years of age gave reduction in stand and yield. Funk et al (1962) found that weak seed produced slower emergence, had less seedling vigour, reduced competitive ability and lower yield than high quality seed as tested by the "cold test" method of vigour assessment.

Further experiments should be carried out by using greater differences in the interim count between high and low vigour and in a larger number of species in order to find the significance of the interim figures used in the present procedure of testing.

3. LABORATORY EXPERIMENT

In order to study the response of vigour of seed to soil temperature and moisture a laboratory experiment was carried out after the field experiment.

3.1 Material and methods -

3.1.1 Layout of the experiment - A factorial design with 3 replications except for the seed imbibition for which 6 replications were used. Treatments were:

(a) Soil temperatures of 20°C and 27°C
(b) 3 soil moistures, 12%, 18% and 22%
(c) 2 varieties, PX610 and XL45
(d) 2 levels of vigour, low vigour and high vigour.

3.1.2 Soil preparation - The soil used was taken from the surface soil of the field experimental plots then air dried for 10 days. The soil was then screened through ½ sq in sieve to eliminate the big lumps and plant material. Soil moisture content of air dried soil was determined.

Amounts of water were added and mixed well to obtain 12%, 18% and 22%. 25 seeds were sown in soil in plastic flower pots. The pots were 12.5 x 12.5 cm at the top and 7.5 x 7.5^2 cm bottom and 10 cm deep. Seeds were covered with the same soil approximately 5 cm deep. After sowing the pots were weighed. Pots were then placed in cabinet germinators at 20°C and 27°C.

To maintain soil moisture, pots were selected at random, weighed, water was added to the pots to make up the amount lost.

3.1.3 Experimental methods -

(a) Seedling emergence - Emergence of seedlings from the soil was recorded daily until no additional seedlings emerged. Seedling emergence was expressed as percentage of emerged seedlings to the total seeds (25 seeds) sown.
Speed of emergence was calculated by following formulae which were modified from Timson (1967):

$$\text{Speed of germination} = \frac{A_1}{T_1} + \frac{A_2}{T_2} \ldots\ldots\ldots + \frac{An}{Tn}$$

A_1, A_2 and An = accumulated seedling emergence at T_1, T_2 & Tn.

T_1, Tn = days from sowing.

For the comparison between treatments, the difference is expressed in relative percentage of the highest speed of germination being 100%.

(b) Imbibition - at 24, 36 and 48 hours after planting 6 pots from each treatment were taken. The seeds were separated from the soil, then washed to remove soil and surface dried with a towel. The seeds were weighed and then dried at 110°C for 2 days. Imbibition was expressed as percentage of moisture to dry weight of seeds.

(c) Utilisation of the reserve food - Endosperm dry matter was determined at 1, 2, 3, 5, 8 and 14 days after sowing. Three pots from each treatment at each sampling were taken. The seedling or embryo was taken off and discarded. The rest of the kernel was then dried at 110°C and weighed. Dry matter was expressed as a percentage of dry matter left in the kernels to the original dry matter.

(d) The growth of roots and shoots - The length of the primary roots was measured after planting at 36 hours, 2, 3, and 5 days. The length was categorized as shown in Figures 13 and 14.
The shoot length was measured at 3, 5, 8 and 14 days after planting. Shoot length was from the point attached to the root to the tip of the highest leaf. The total length of roots and shoots was calculated by multimplying the medium length in each category by the number of seedlings, sum all the length and then average from 25 seeds sown and used in the analysis of variance.

3.1.4 Statistical method - All the analysis described below was carried out with the aid of the Massey University IBM 1130 computer.

The results indicated the seedling emergence, dry matter of seed, imbibition needed aresin transformation within each sampling time. Analysis of variance for factorial was used.

The least significant difference for treatment comparisons between various means were calculated according to the formula presented by Cochran and Cox (1957). The co-efficient of variation is outlined by Snedecor and Cochran (1967).

3.2 RESULTS

In this chapter the results from the experiment under controlled conditions are presented in order of imbibition of the seed, seedling emergence, speed of germination, the utilisation of the endosperm and the growth of seedling.

3.2.1 Imbibition - The original moisture content of the seed prior to sowing is shown in Table 10.

Table 10: Moisture content of seed.

Variety	PX610		XL45	
Vigour	High	Low	High	Low
Moisture %	13.76	13.52	13.93	12.84

The analysis of variance reveals significant soil moisture, temperature, variety and vigour effects on the imbibition of the seed following sowing expressed as a percentage of absorbed water to dry weight (Appendix 13).

The effects of soil moisture levels on the moisture percentage of seed are presented in Table 11 a:

Table 11 a: The effect of soil moisture on imbibition.

Time	Seed Moisture %						LSD 5%+
	Soil Moisture Levels						
	12%		18%		22%		
24 h	40.85++	(43%)+++	42.81	(46%)	43.04	(47%)	.07
36 h	43.37	(47%)	46.34	(52%)	45.96	(51%)	.59
48 h	45.21	(50%)	48.82	(57%)	50.37	(59%)	.64

LSD+ 5% for comparison between soil moisture levels.

++ Arcsin value

( )+++ equivalent percentage to the arcsin value.

Table 11b: The effect of temperature, variety and vigour level on imbibition.

Time (hours)	Temperature	% Seed Moisture	Variety	% Seed Moisture	Vigour	% Seed Moisture	LSD^{+} 5%
24	20°C	41.99^{++} $(45\%)^{+++}$	PX610	41.16 (43%)	High	41.86 (45%)	.58
	27°C	42.48 (46%)	XL45	43.26 (48%)	Low	42.56 (46%)	
36	20°C	44.38 (49%)	PX610	44.34 (49%)	High	45.72 (50%)	.51
	27°C	46.07 (52%)	XL45	46.10 (52%)	Low	44.72 (50%)	
48	20°C	45.65 (51%)	PX610	47.57 (55%)	High	48.79 (57%)	.73
	27°C	50.61 (60%)	XL45	48.69 (56%)	Low	47.47 (54%)	

LSD^{+} 5% for comparison between temperature, varieties and levels of vigour within a date of sampling.

++ Arcsin value

+++ equivalent percentage to the arcsin value.

More moisture was absorbed by the seeds sown in 18% and 22% than in 12% soil moisture. There was no significant difference between moisture imbibed by seeds sown at 18% and 22% soil moistures until 48 hours after sowing.

The effects of air temperature, maize variety and seed vigour on seed moisture percentage are presented in Table 11 b.

It is obvious that the higher temperature, 27°C, has a greater effect on imbibition of seed.

The seed of XL45 absorbed more water than PX610 at all times of sampling and during the first 24 hours, low vigour seeds absorbed more moisture than the high vigour seeds. However from 24 hours to 48 hours more moisture was absorbed by the high vigour seeds. As shown in Table 12 this change in seed moisture level with time was confined to the PX610 variety and was not reflected in the XL45 variety.

Table 12: The effect of varieties and vigour on imbibition.

Time (hours)	Vigour	Moisture Content %		LSD 5%
		Varieties		
		PX610	XL45	
24	High	40.14^{++} (41%)$^{+++}$	42.75 (47%)	.80
	Low	42.17 (45%)	43.58 (48%)	
36	High	45.76 (51%)	45.69 (51%)	.68
	Low	42.92 (46%)	46.52 (53%)	
48	High	49.01 (57%)	48.57 (56%)	1.04
	Low	46.14 (52%)	48.81 (57%)	

LSD^{+} 5% for comparison of the vigour at a given variety and varieties at a given vigour.

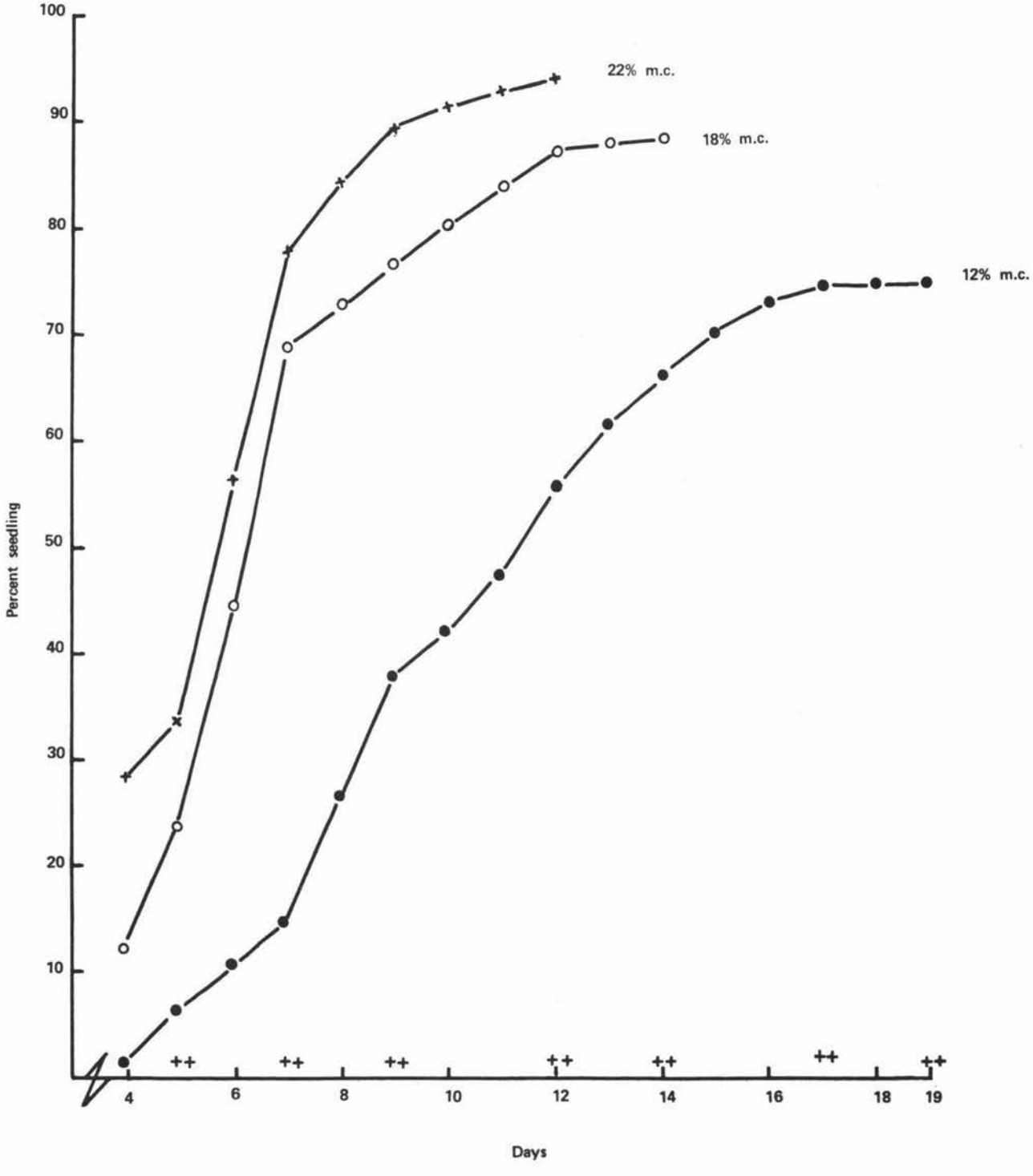
$^{++}$ Arcsin value.

( )$^{+++}$ Equivalent percentage to the arcsin value.

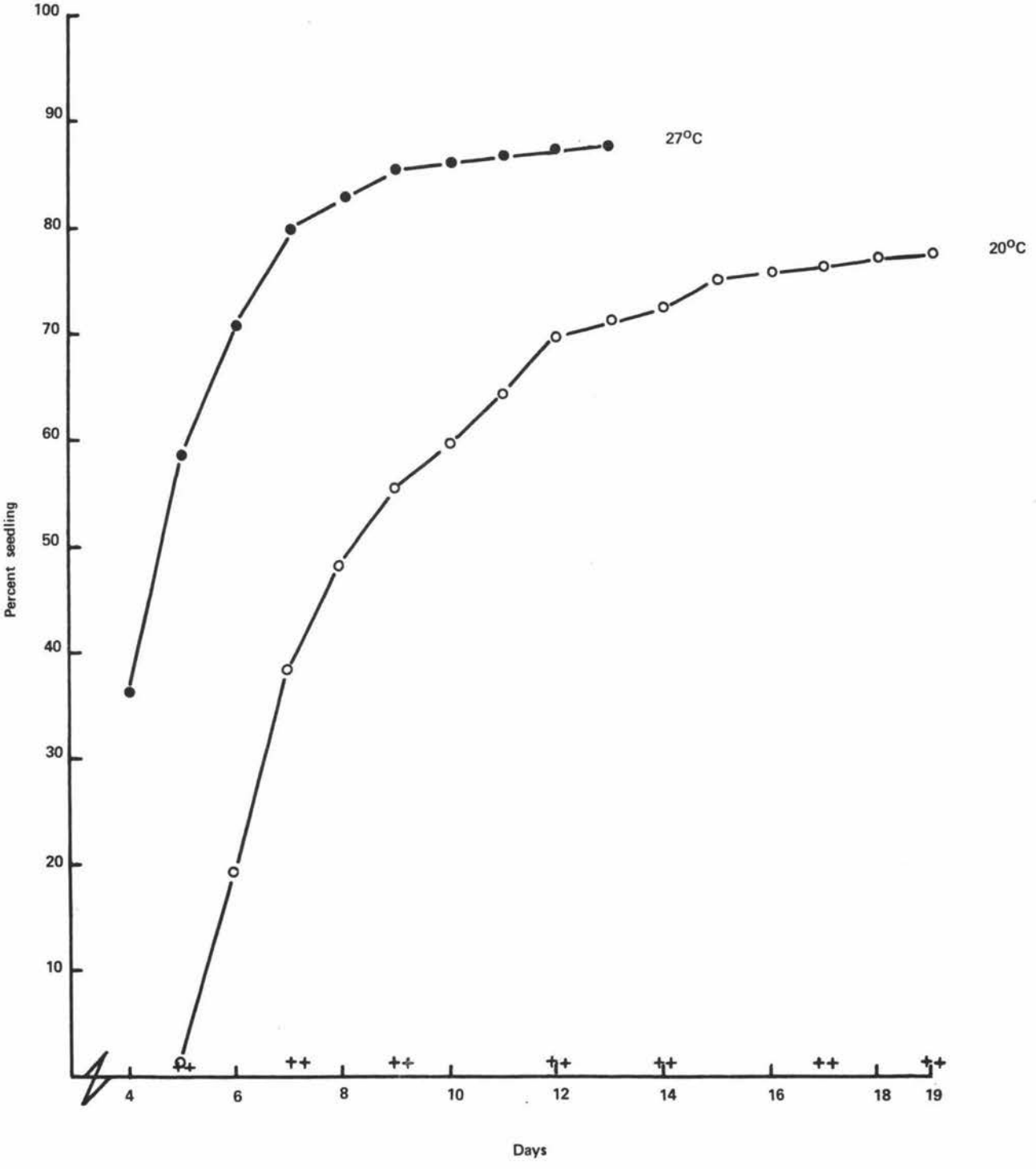
3.2.2 Seedling emergence under controlled conditions - The analysis of variance of seedling emergence at the following dates 5, 7, 9, 12, 14, 17

FIG. 7 SEEDLING EMERGENCE

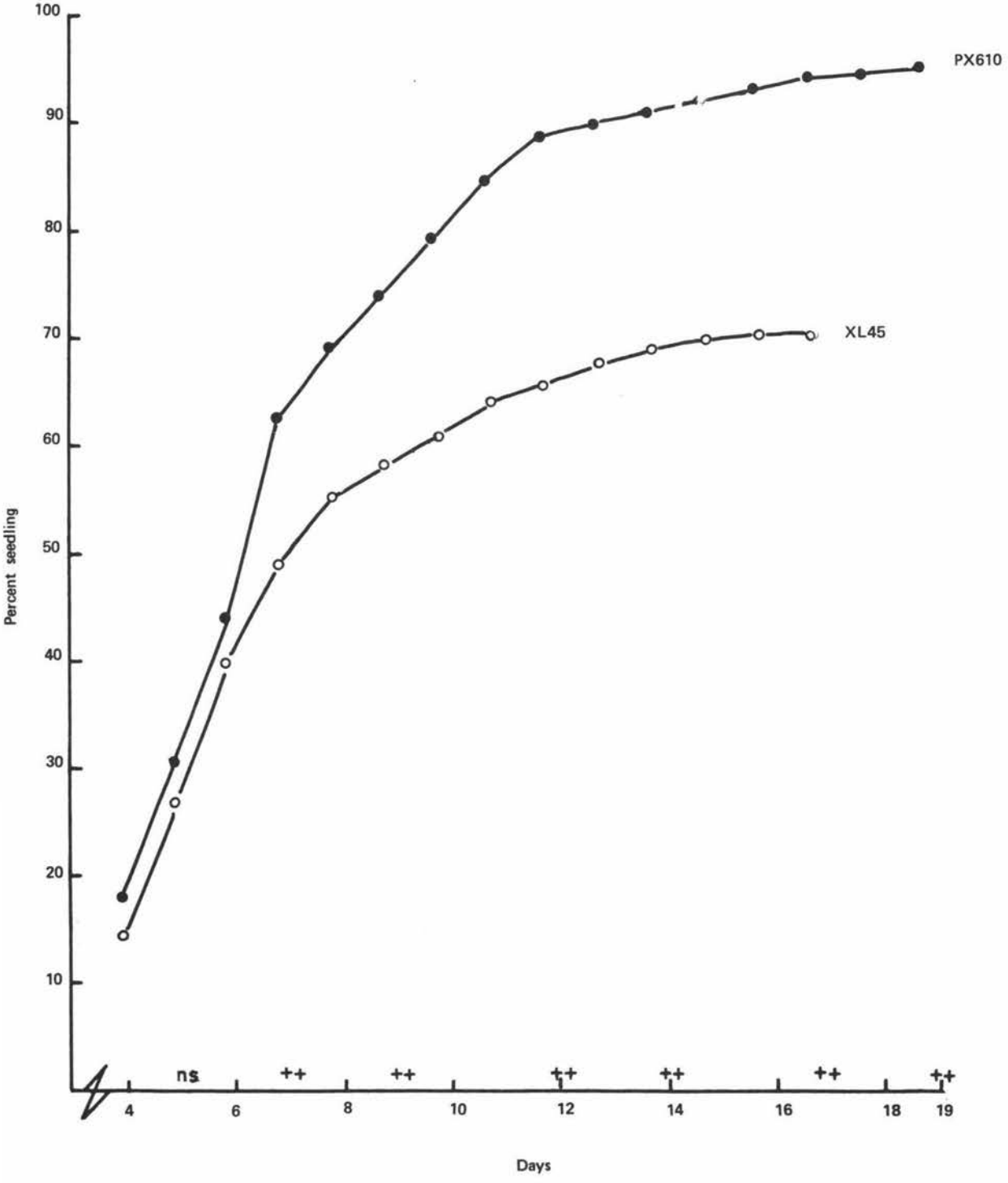
(a) Seedling emergence from 12%, 18% and 22% soil moistures



(b) Seedling emergence at 20°C and 27°C temperatures



(c) Seedling emergence of varieties PX610 and XL45



(d) The effect of high and low vigour on seedling emergence

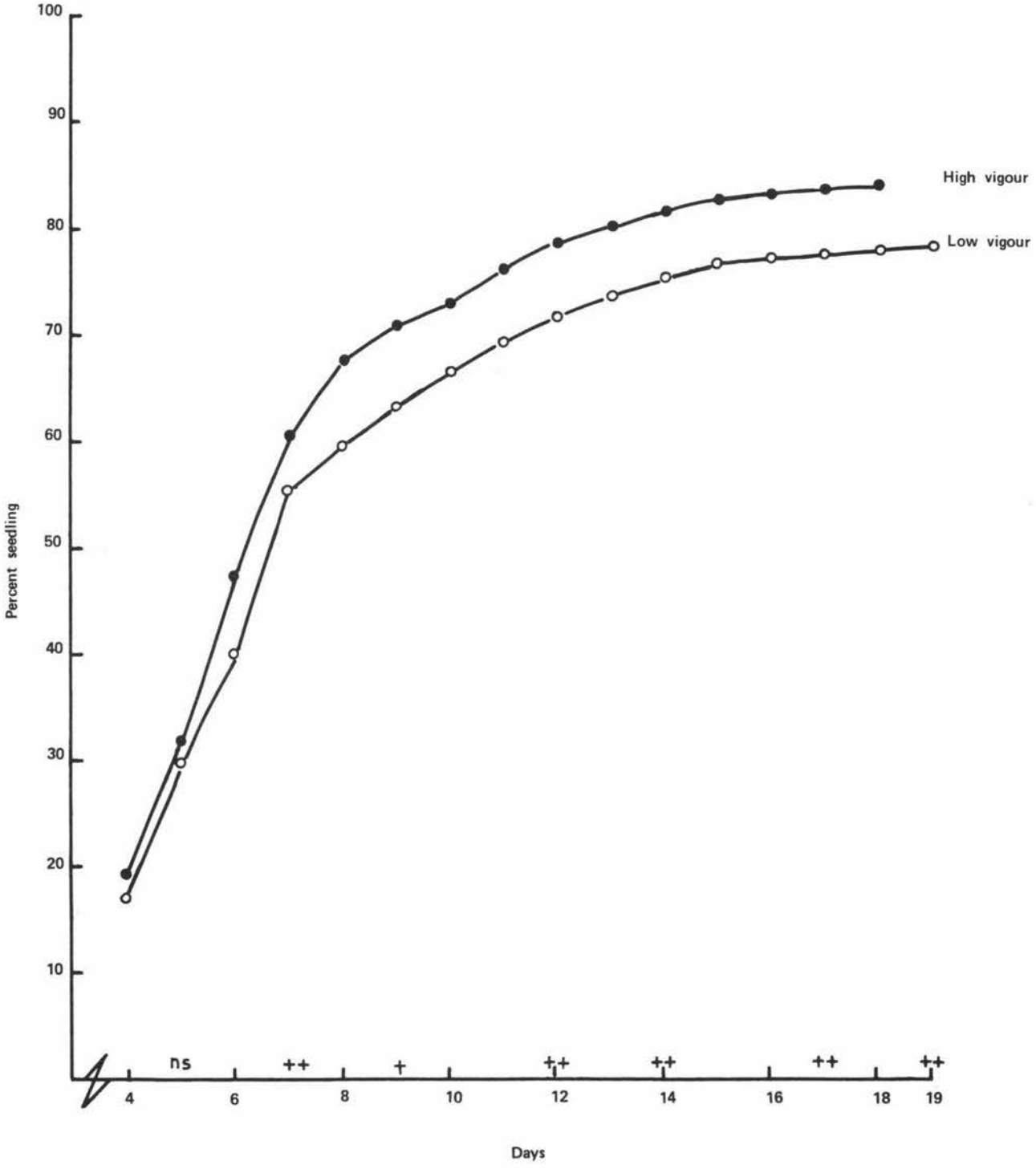
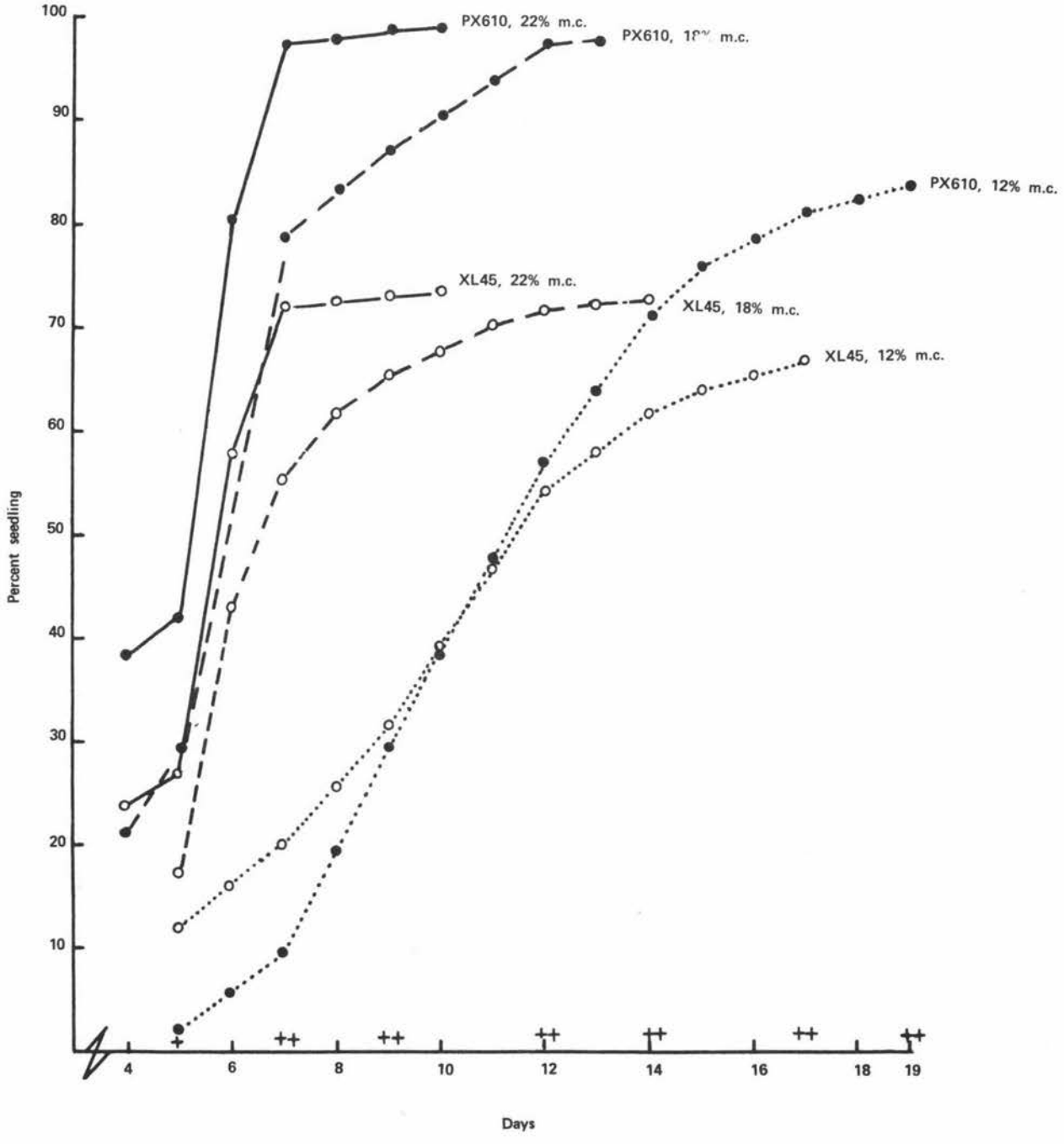


FIG. 8 SEEDLING EMERGENCE OF VARIETIES PX610 and XL45 at 12%, 18% and 22% SOIL MOISTURES



and 19 days after sowing is shown in Appendix 14.

Highly significant soil moisture, temperature, variety and vigour effects on the rate of seedling emergence were recorded and are shown in Figure 7 a, b, c and d. The effects of variety and vigour were very pronounced at the 7th day and after till the end of the emergence period on the 19th day.

The emergence of seedlings was highest at 22% soil moisture which was significantly higher than 18% and 12% up to 7 days after sowing. From 9 days till the end of the emergence period although the emergence of seedlings was higher at 22% soil moisture, there was no significant difference between 18% and 22%. Seedling emergence was ranked in the order of 22%, 18% and 12% soil moisture for all emergence dates recorded (Figure 7 a).

The emergence of seedlings at 27°C was a day earlier than 20°C and was completed in a shorter time, 14 days and 19 days respectively (Figure 7 b). At 27°C, 36% of seedlings emerged on the 4th day, whereas only 18% had emerged at 20°C on the 5th day. Most of the seedlings (80%) emerged within 7 days after sowing at 27°C whereas only 32.6% emerged at 20°C.

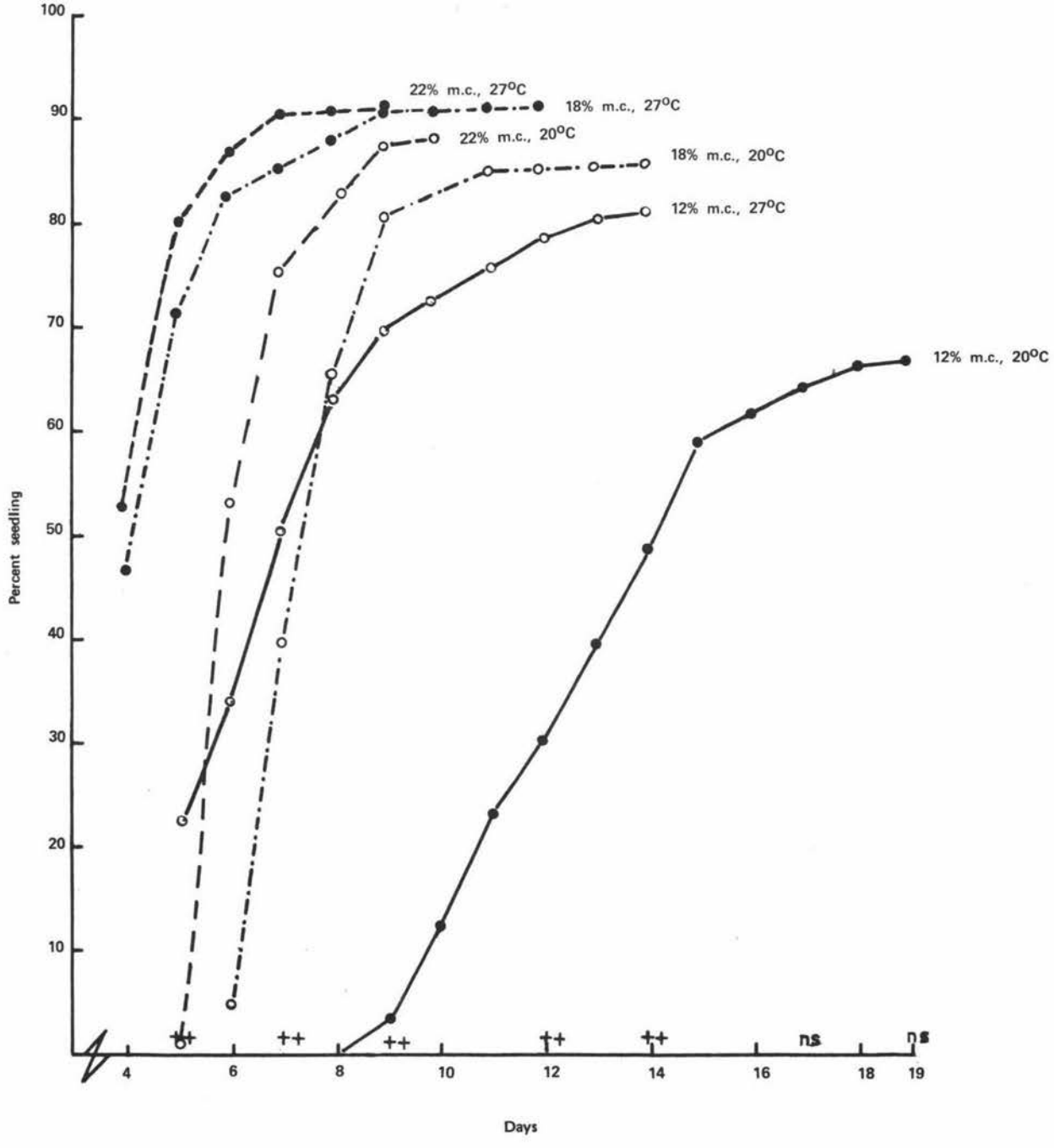
Higher percentage emergence of PX610 than XL45 was revealed 7 days after sowing till the emergence was completed (Figure 7 c). The emergence of both varieties increased rapidly during the first 7 days reaching 65% and 50% for PX610 and XL45 respectively, then the rate of increase declined as the final emergence was approached. The total emergence of PX610 reached a higher percentage than XL45 (95.3% 73.3%).

A significant difference between the higher and low vigour lines is shown in Figure 7 d and commenced from 7 days after planting till the end of the emergence period, with higher emergence from the high vigour seed.

The significant interaction of soil moisture and variety on seedling emergence is presented in Figure 8 (Appendix 19). At 12% soil moisture, seedling emergence of XL45 was higher than PX610 up to 9 days after sowing. During the 9th to 12th days the emergence of PX610 increased rapidly and resulted in higher emergence percentage than XL45.

At 18% soil moisture, seedling emergence of PX610 started a day earlier than XL45. There was higher emergence from PX610 than XL45 and the

FIG. 9 THE EFFECT OF MOISTURES AND TEMPERATURES ON EMERGENCE OF SEEDLING



difference was significant from 7 days after sowing. The same trend was also apparent at 22% soil moisture.

It can also be seen that the higher soil moisture level tended to hasten the emergence of seedlings, shorten the emergence period and achieve a high emergence percentage than in the lower soil moisture treatments.

A high significant interaction between temperature and moisture levels is presented in Figure 9 (Appendix 24). As can be seen, temperature had little effect on seedling emergence at 22% soil moisture level but at lower moisture levels the higher air temperature (27°C) significantly increased seedling emergence compared with the lower temperature (20°C).

3.2.3 Speed of emergence - Speed of emergence of seedling was significantly affected by moisture, temperature, variety and vigour (Table 13, Appendix 14).

Table 13: Speed of seedling emergence.

Variable	Speed of Emergence	(Relative figures)	LSD 5%
Soil Moisture 12%	60.08+	(49%)++	
18%	109.21	(90%)	6.70
22%	121.53	(100%)	
Temperature 20°C	70.78	(58%)	5.47
27°C	123.04	(100%)	
Variety PX610	107.23	(100%)	5.47
XL45	86.64	(87%)	
Vigour High	101.42	(100%)	5.47
Low	92.45	(91%)	

( )++ relative percentage of speed of emergence (which is relative to the 22% soil moisture treatment at 100%).

The higher the soil moisture and the temperature the faster the speed of emergence. As shown in Table 14 the speed of seedling emergence in the 22% soil moisture treatment was twice as fast as in 12% moisture treatment. Similarly at 27°C the speed of emergence was almost twice that

at 20°C. The speed of emergence of PX610 was higher than XL45 and the high vigour line faster than the low vigour line.

However, as presented in Table 14, there was a significant interaction between variety, soil moisture and temperature. For example although PX610 had a faster speed of emergence than XL45 at 18% and 22% soil moisture levels, there was no significant difference between the two varieties at 12% soil moisture. It is also apparent that the 27°C treatment was relatively more effective in increased speed of seedling emergence at 12% soil moisture level than at 22% soil moisture.

The speed of germination increased as temperature and moisture level increased but there was no difference between 18% and 22% soil moisture at 27°C.

Table 14: The interaction effects of soil moisture with maize variety and temperature.

Variable	Speed of emergence (% seedling/days)			LSD+ 5%
	Soil Moisture			
	12%	18%	22%	
Variety PX610	56.75 (40%)	124.26 (88%)	140.69 (100%)	9.48
XL45	63.41 (45%)	94.16 (67%)	102.36 (73%)	
Temperature 20°C	31.09 (22%)	79.97 (56%)	101.28 (71%)	9.48
27°C	89.06 (63%)	138.45 (98%)	141.77 (100%)	

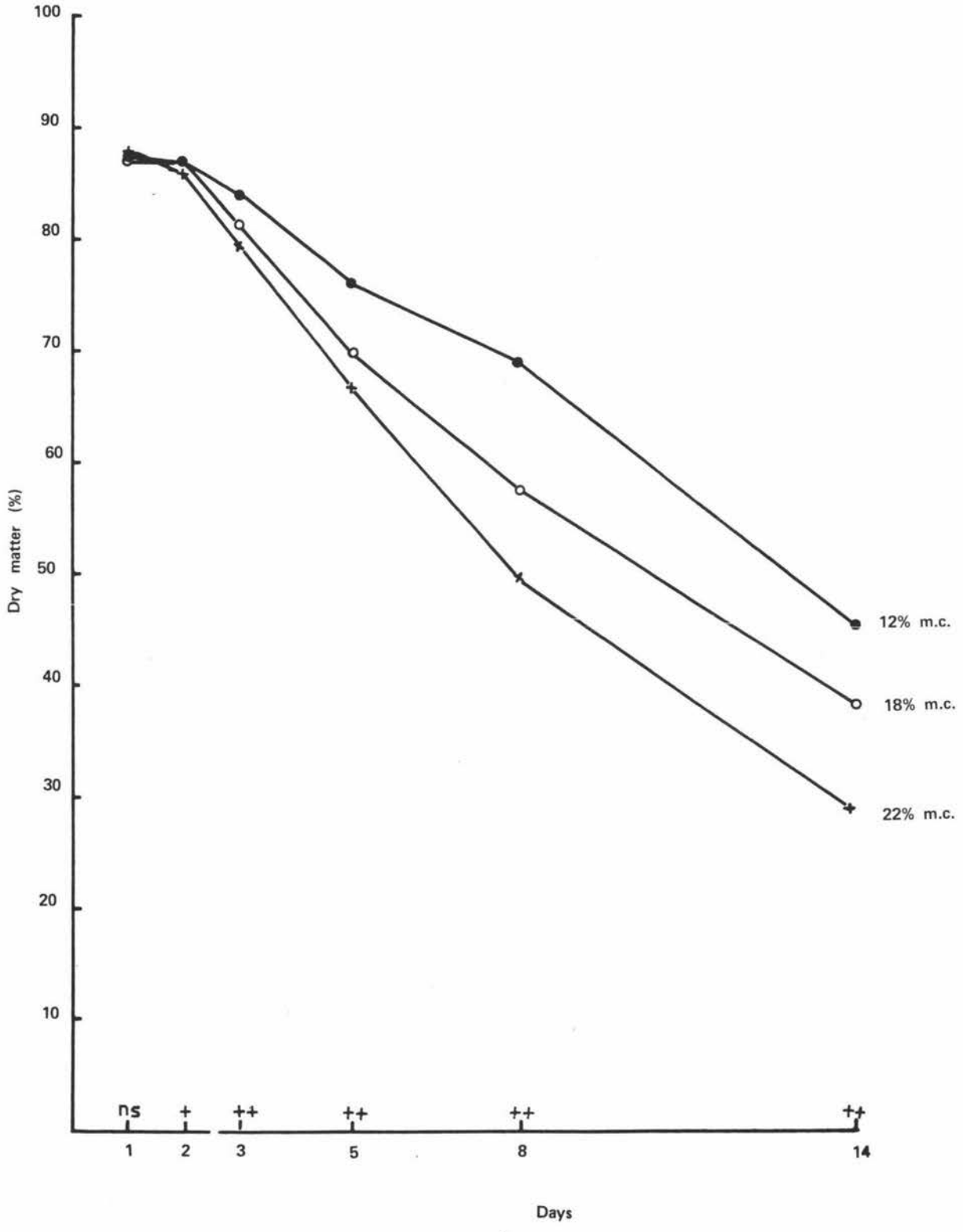
LSD+ 5% for the comparison between soil moistures at a given variety and a given temperature and for the comparison between varieties, temperature at given moisture.

( )++ relative percentage to the treatment with the highest speed of germination.

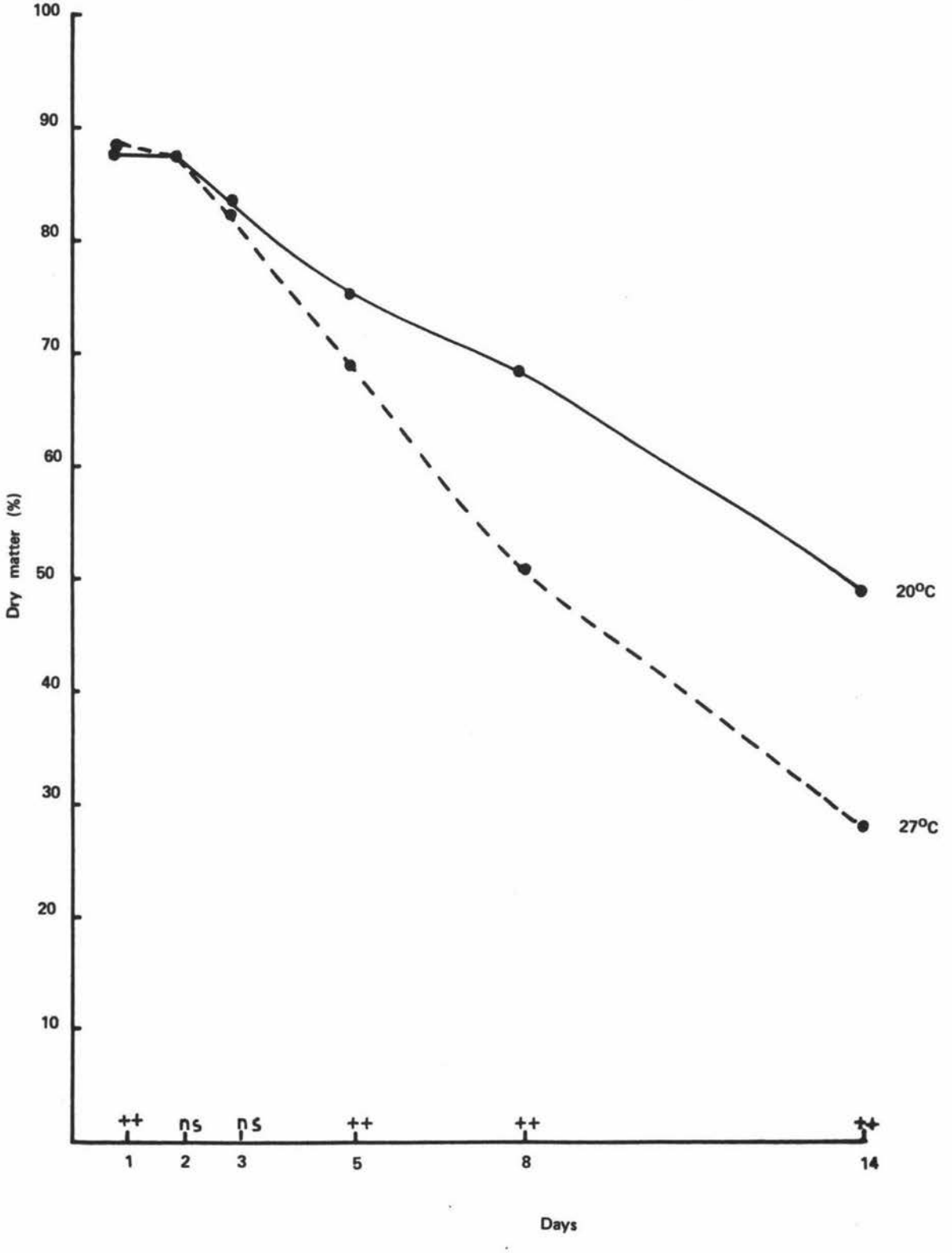
3.2.4 The utilisation of the endosperm - The utilisation of the endosperm expressed as percentage of dry weight left in the kernel on 1, 2, 3, 5, 8 and 14 days after planting was measured. The original dry matter level of the seed is presented in Table 15, the effects of treatments on endosperm dry matter are shown in Figure 10 a, b, c and d and the analysis of variance in Appendix 21.

FIG. 10 THE UTILIZATION OF THE ENDOSPERM

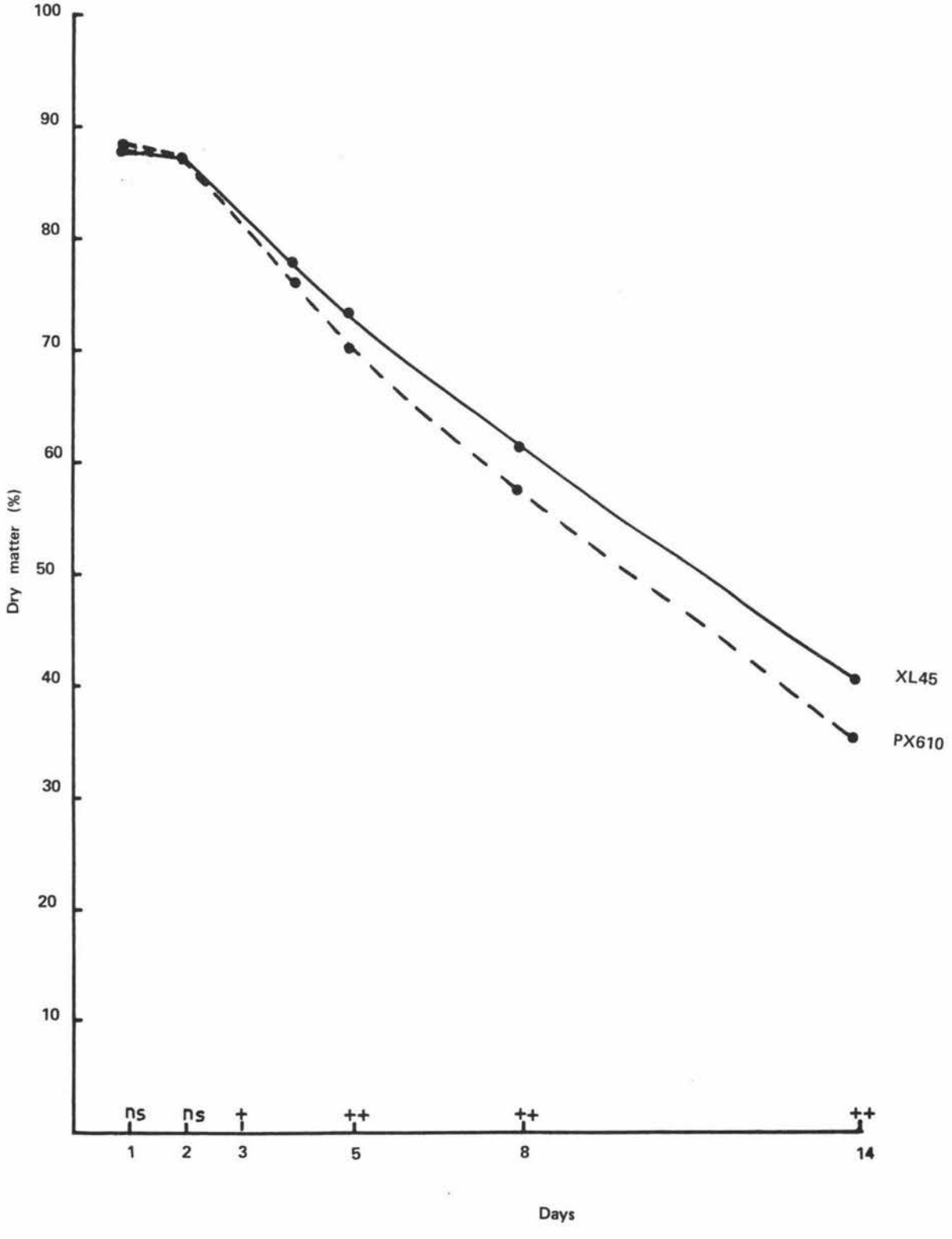
(a) The endosperm dry matter of seeds sown at 12%, 18% and 22% soil moisture



(b) The endosperm dry matter of seeds sown at 20°C and 27°C temperatures



(c) The dry matter of the endosperm of PX610 and XL45



(d) The endosperm dry matter of high and low vigour

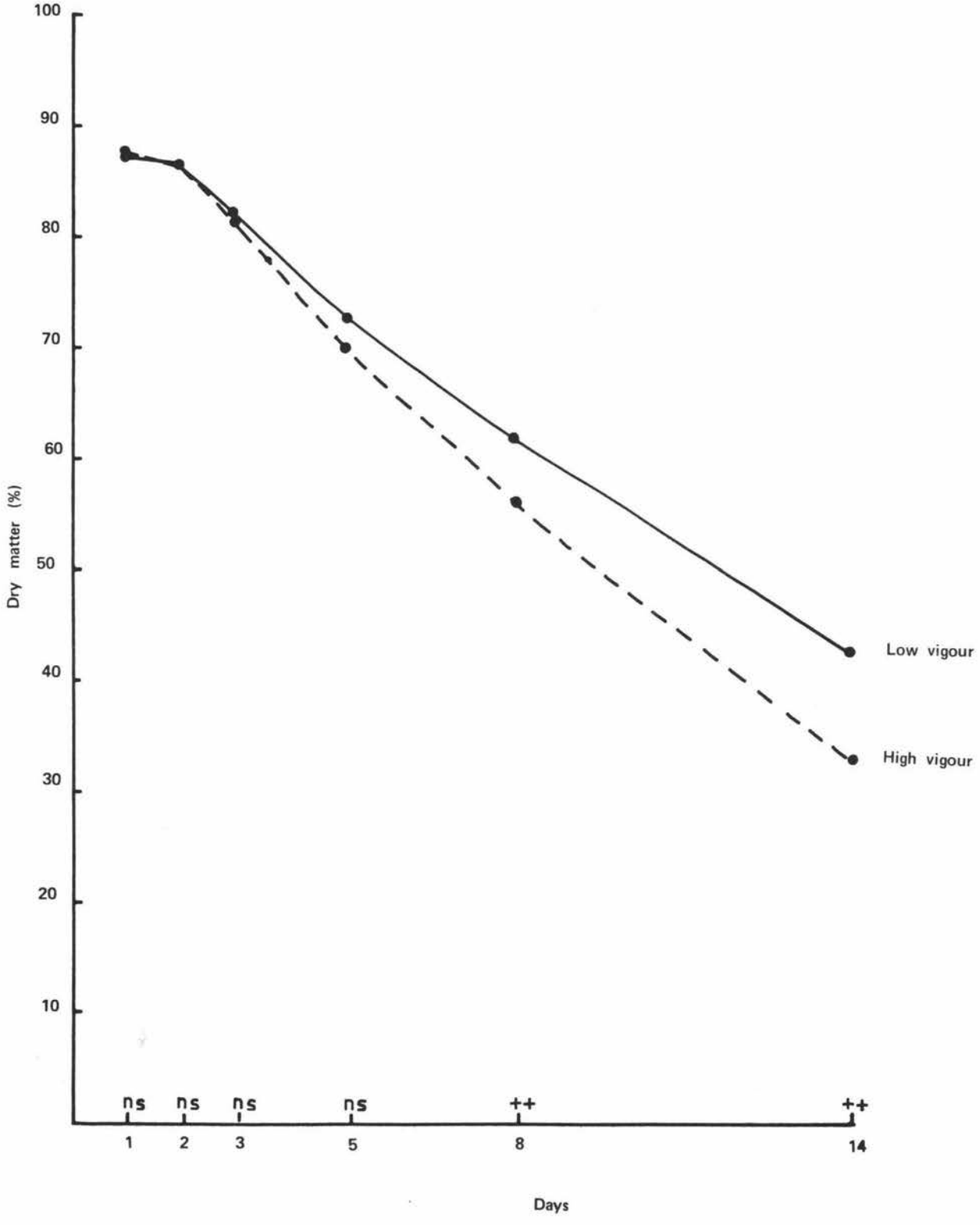


Table 15: The original dry matter of the seeds.

Variety	PX610		XL45	
Vigour	High	Low	High	Low
Dry matter %	87.77	87.71	87.64	88.08

Both varieties had a similar amount of food reserve in the endosperm.

The effect of soil moisture on the utilisation of endosperm is presented in Figure 10 a, and shows that the higher soil moisture content the faster the utilisation of the endosperm following the first 2 to 3 days.

Highly significant temperature effect appeared from the 5th day onwards (Figure 10b, Appendix 22). Higher utilisation of the endosperm was from the seed sown at the higher temperature (27°C).

Higher utilisation of the endosperm of the variety PX610 than XL45 was found 3 days after sowing till the end of the experiment (Figure 10 c). Similarly seed of the higher vigour line utilised the endosperm dry matter at a faster rate than that of the low vigour line, which was noticeable 5 days after sowing (Figure 10 d).

A highly significant moisture/temperature interaction is presented in Figure 11. While the dry matter percentage of the seed held at 27°C declined more rapidly than that at 20°C, this effect occurred to a significant extent in the 22% soil moisture treatment after only 2 days and only at 27°C. However by the 8th day all treatments showed significant differences in dry matter levels. In other words the utilisation of the endosperm occurred more rapidly at the higher temperature and highest moisture level compared with a slower rate of decline at the lower temperature and lower soil moisture levels. By the end of the period there was little difference in endosperm dry matter between the soil moisture levels at 27°C but large differences still evident between soil moisture levels at 20°C.

The significant interaction between the two varieties and vigour lines is presented in Figure 12. As shown while the dry matter level of

FIG. 11 THE EFFECT OF MOISTURE AND TEMPERATURE ON THE ENDOSPERM DRY MATTER AFTER SOWING

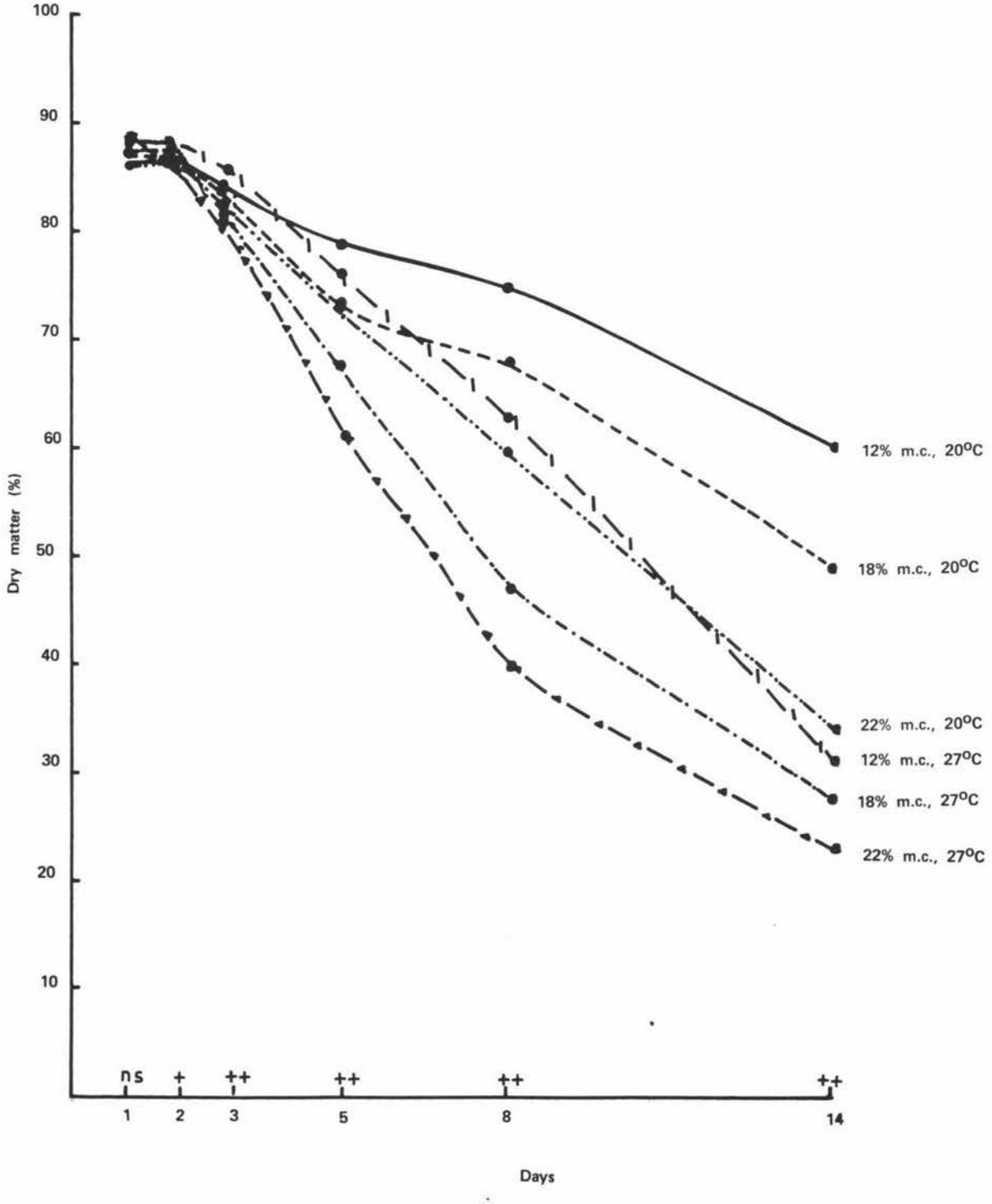
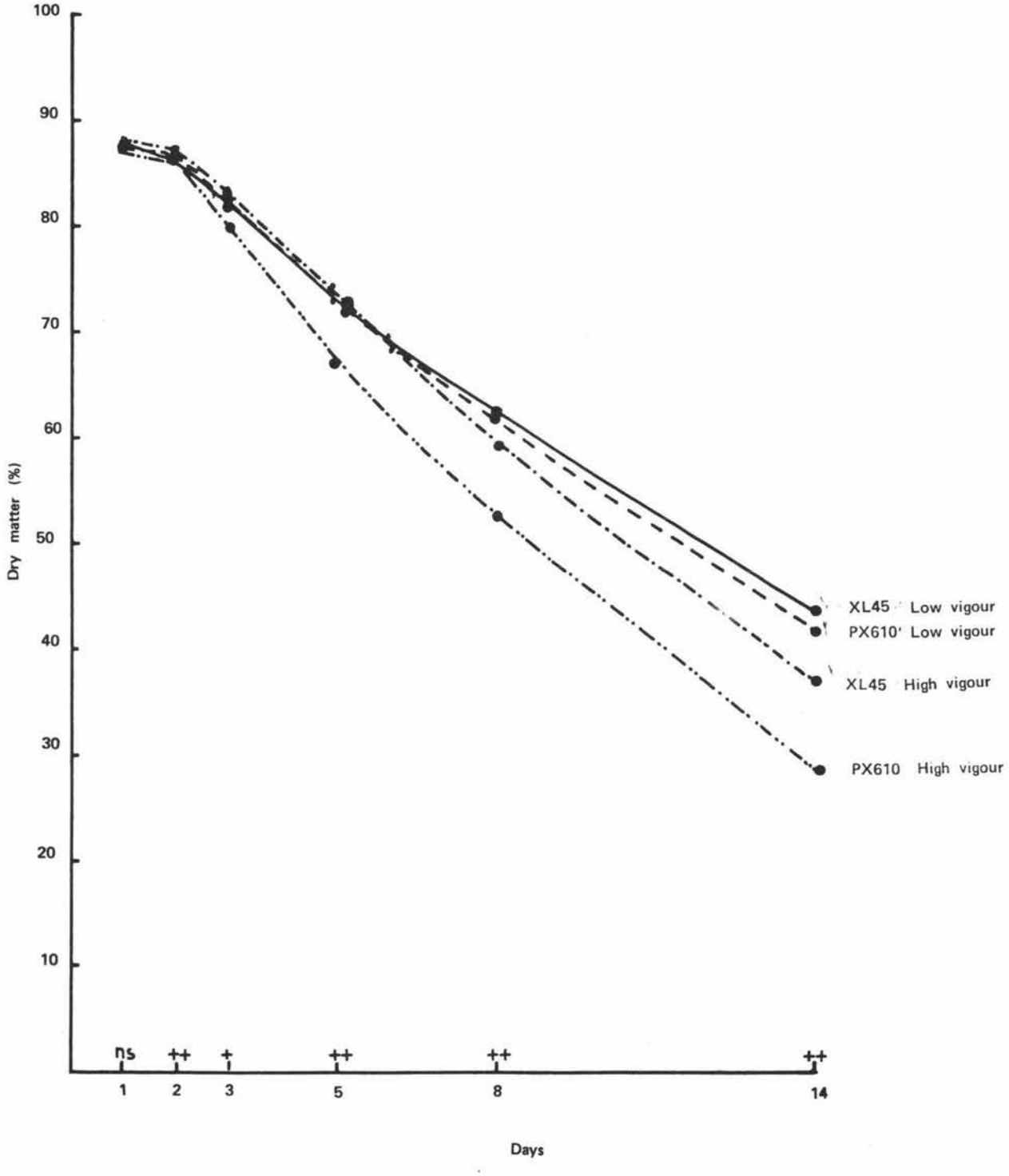


FIG. 12 THE ENDOSPERM DRY MATTER OF THE HIGH AND LOW VIGOUR OF PX610 AND XL45 AFTER SOWING



the PX610 variety declined at a faster rate than the XL45 variety, this was only apparent in the high vigour line. After 14 days there was no significant difference in dry matter percentage between PX610 and XL45 low vigour lines.

3.2.5 Root and shoot growth -

(a) Root growth: The root is the first part of the embryo to emerge from the maize seed.

Table 16 a: The effect of soil moisture on the growth of the roots.

Time	Average root length (cm)			LSD 5%
	Soil Moisture			
	12%	18%	22%	
36 hours	.03	.11	.13	.02
48 hours	.10	.41	.53	.06
3 days	.78	1.9	2.06	.20
5 days	3.04	4.45	4.85	.34

As shown in Table 16 a soil moisture levels significantly affected root growth with the seedling in the highest soil moisture treatment having the longest root. This difference due to soil moisture tended to narrow with time.

Seeds sown in higher temperature conditions (27°C) produced roots sooner and longer than seeds sown at lower temperature. It is interesting to note in Table 16 b that root appearance occurred within 36 hours in the 27°C treatment but at 20°C it took almost 3 days.

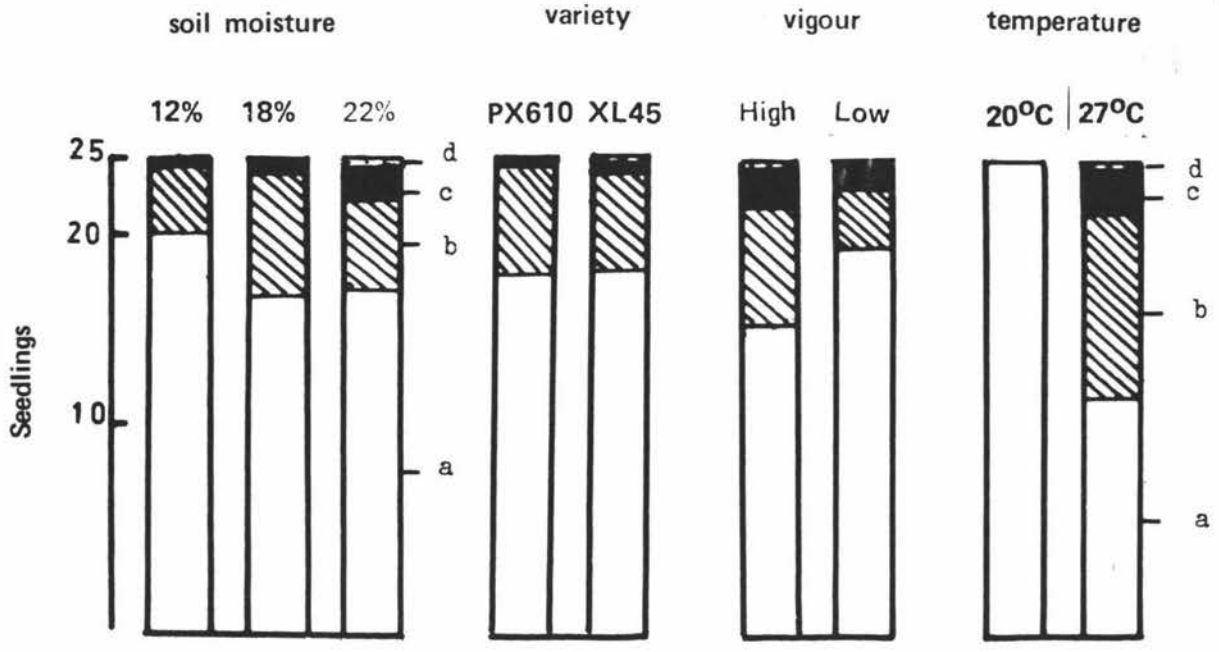
Also shown in Table 16 b is that seedlings of PX610 had significantly longer roots than XL45, the difference being considerable by the 3rd day.

Similarly the high vigour seedlings had significantly longer roots than the low vigour seedlings.

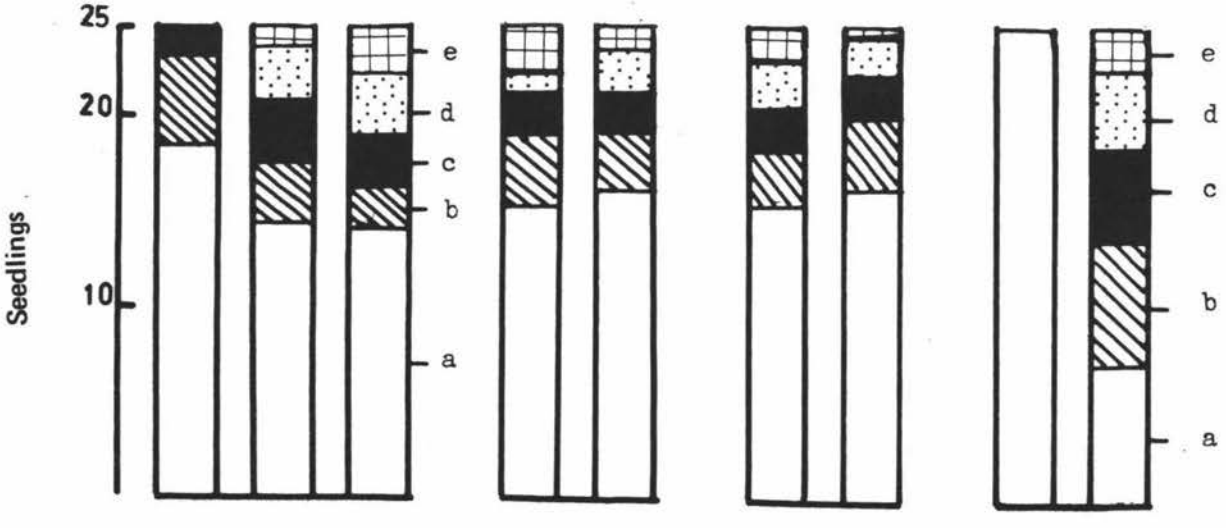
The number of seedlings (out of 25) having roots of different lengths are shown in Figure 13. Broadly speaking the higher temperature (27°C), the higher vigour line and the higher soil moisture levels (22%

FIG. 13 ROOT LENGTH

a = O b = >O–½ c = ½–1 d = 1–2 e = 2–4 cms



36hours



48hours

FIG. 13 Continued

a = O, b = >O–3, c = 3–10, d = 10–15, e = 15–20 cms

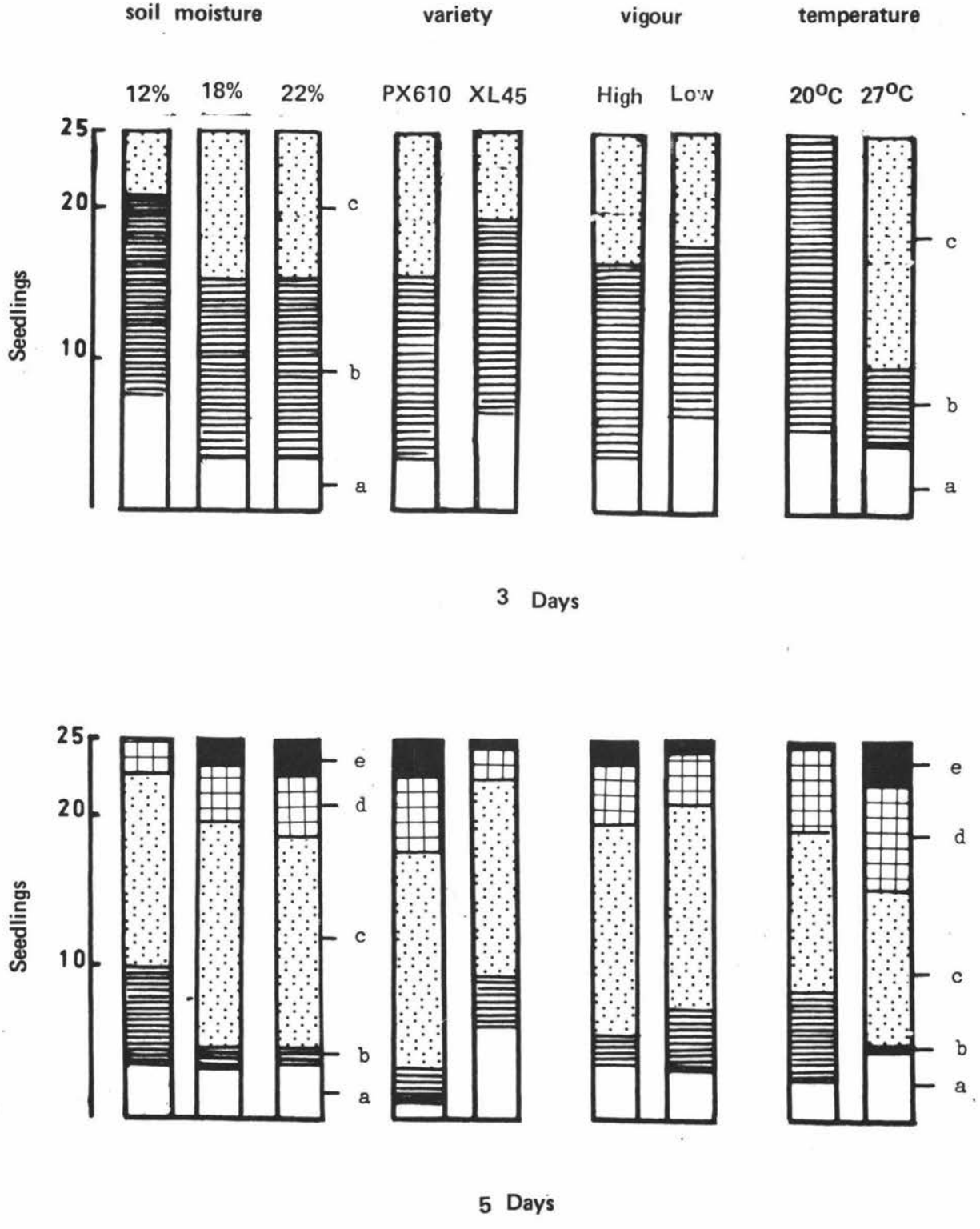


Table 16 b: The average root length of the significant response of temperature, variety and moisture.

Time	Temperature (C^0)	Average Root Length (cm)	Variety	Average Root Length (cm)	Vigour	Average Root Length (cm)	LSD^+ 5%
36 hours	20	0.0	PX610	0.08	High	0.12	0.01
	27	0.18	XL45	0.10	Low	0.06	
48 hours	20	0.0	PX610	0.70	High	0.43	0.05
	27	0.69	XL45	0.68	Low	0.26	
3 days	20	0.75	PX610	3.01	High	2.68	0.18
	27	3.99	XL45	1.73	Low	2.06	
5 days	20	4.36	PX610	7.65	High	6.63	0.28
	27	7.94	XL45	4.65	Low	5.67	

LSD^+ 5% for comparison between temperature, varieties and vigours within a date of sampling.

NS^{++} No significant difference between the two varieties.

FIG. 14 EFFECT OF MOISTURE AND TEMPERATURE ON ROOT LENGTH

a = O b = >O–½ c = ½–1 d = 1–2 e = 2–4 cms

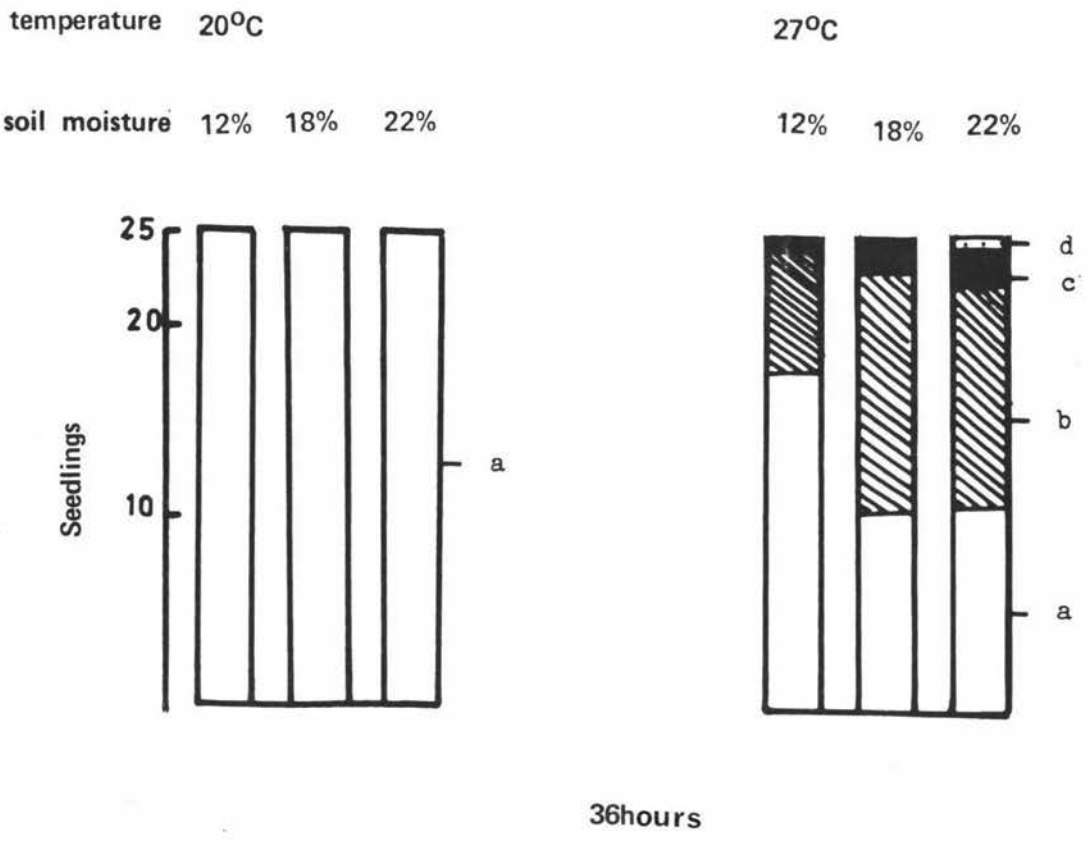
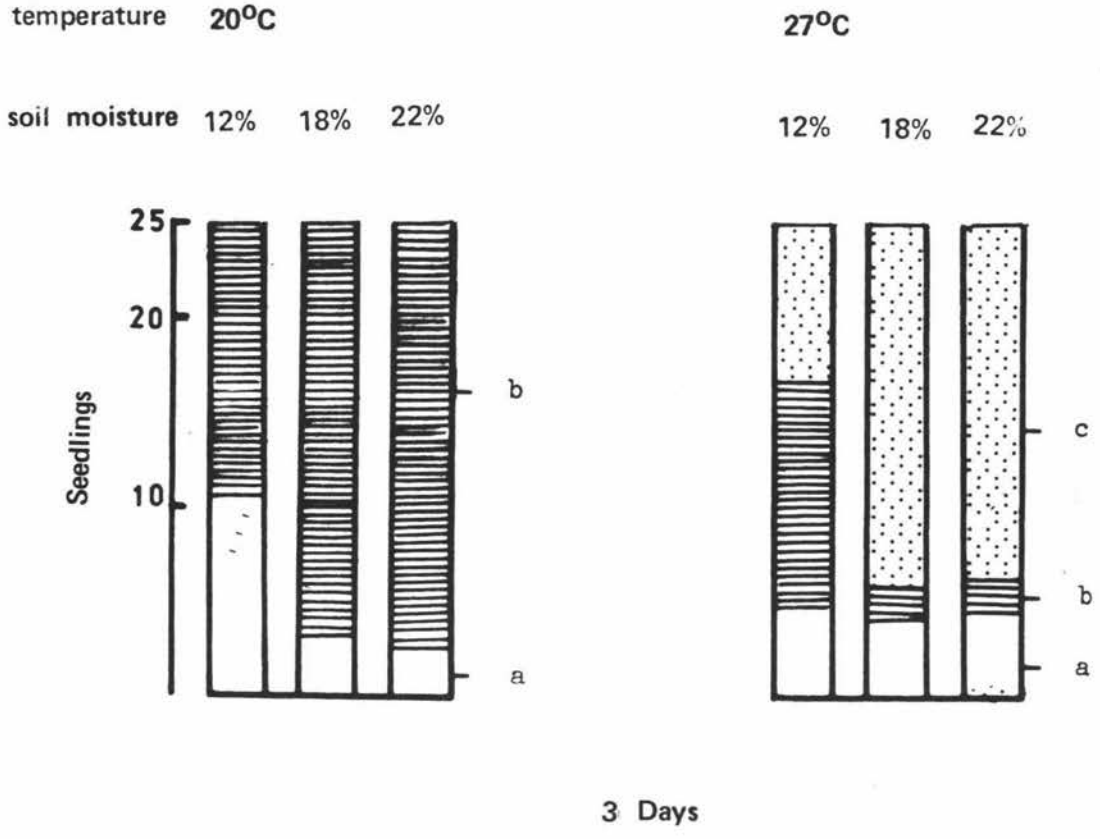


FIG. 14 Continued

a = O, b = >O–3, c = 3–10, d = 10–15, e = 15–20 cms



and 18%) all stimulated root emergence and extension to a greater extent than remaining comparisons. To a lesser extent PX610 seedlings show the same root superiority over XL45 seedlings.

Highly significant interaction effects of moisture versus temperature, vigour versus temperature and variety versus vigour on the root length are recorded in Appendix 25. The example of responses to these interactions on the 5th day after planting are presented in Table 17.

Table 17: The significant interaction of treatments on root length five days after planting.

Variables	Average root length (cm)		LSD 5%
	Temperatures (C°)		
Moistures	20	27	
12%	2.46	6.67	
18%	4.54	8.67	.48
22%	6.06	8.68	
Vigour	Temperatures (C°)		LSD 5%
	20	27	
High	5.06	8.20	.40
Low	3.66	7.86	
Vigour	Variety		LSD 5%
	PX610	XL45	
High	8.54	4.72	.40
Low	6.79	4.58	

In terms of the temperature and soil moisture interaction root length showed a significant and continuing response to increasing soil moisture level when seedlings were grown at 20°C but showed no significant response beyond 18% soil moisture when grown at 27°C.

The temperature and vigour interaction showed that the superior root length of the high vigour line was very obvious in the 20°C treatment but not in the 27°C treatment.

Similarly the superority of the high vigour line in terms of root length only occurred in the variety PX610 and not in XL45.

(b) Shoot growth: Highly significant effects of all treatments on the average shoot length were revealed in the analysis of variance shown in Appendix 26.

Table 18 a: The significant effect of soil moistures on the shoot length.

Time (days)	Shoot length (cm)			LSD 5%
	Soil Moistures			
	12%	18%	22%	
3	.11	.72	1.08	.09
5	1.13	4.67	6.93	.35
8	2.24	11.28	14.09	.75
14	15.96	21.50	28.29	1.40

As shown in Table 18 a on every date of sampling the effect of soil moisture showed that greater shoot length was from the seed sown in higher soil moisture. The effect was ranked in the order of 22%, 18% and 12%. The histogram (Figure 15) shows that the shoot emerged earliest from higher soil moistures (18% and 22%). The shoots were found to emerge on the 2nd day after planting, by the 3rd day some seedlings were about 3 - 10 cm long at 18% and 22% soil moisture. However there were higher numbers in 22% than in 18% soil moisture. At 12% soil moisture only few seedlings about ½ - 1 cm high on the same day. By the fifth day most of the seeds sown in 18% and 22% moisture had germinated but at 12% seed was still germinating. By 14 days the average shoot lengths were 28, 22 and 16 cm at 22%, 18% and 12% respectively.

Higher average root length was recorded from the seed sown at 27°C than 20°C (Table 18 b). The difference reached a high proportion by the 5th day.

Shoot length of PX610 seedlings was significantly greater than that of XL45; and high vigour lines had longer shoots than low vigour seedlings (Table 18 b).

FIG. 15 SHOOT LENGTH

a = O, b = >O–3, c = 3–10, d = 10–15, e = 15–20 cms

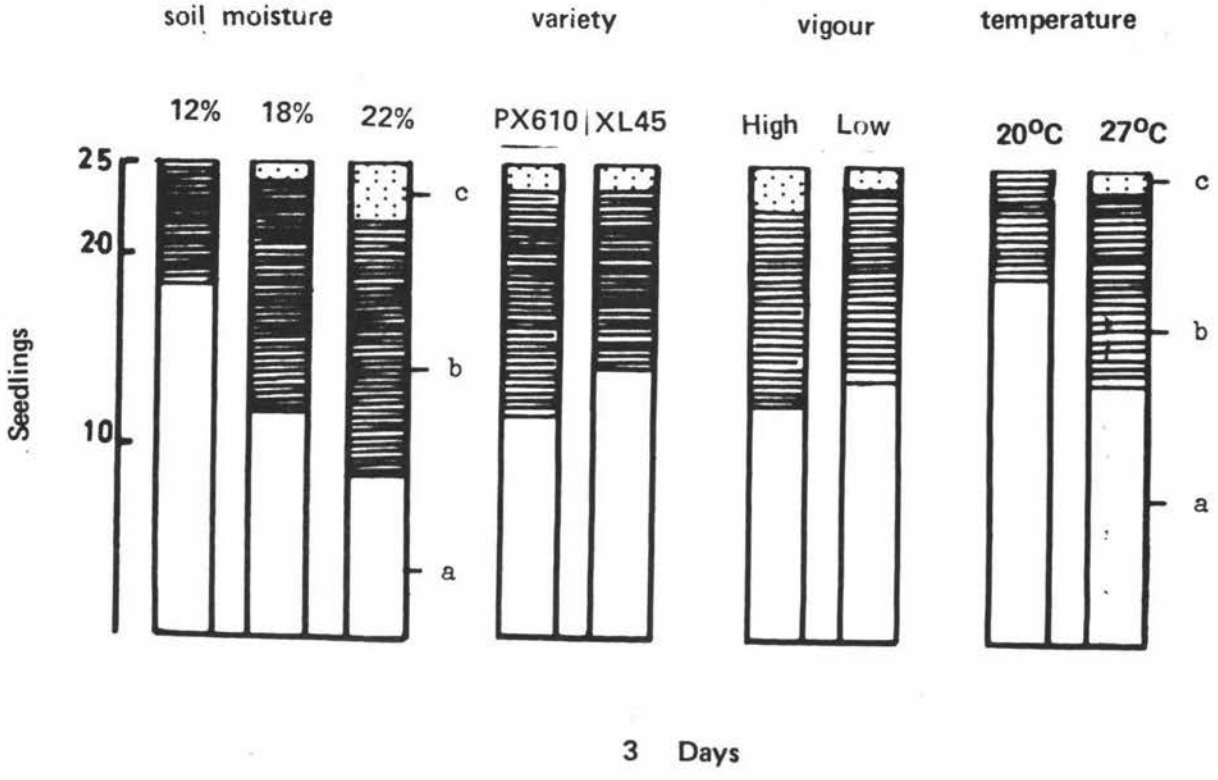


FIG. 15 Continued

a = O, b = >O–5, c = 5–15, d = 15–30, e = >30

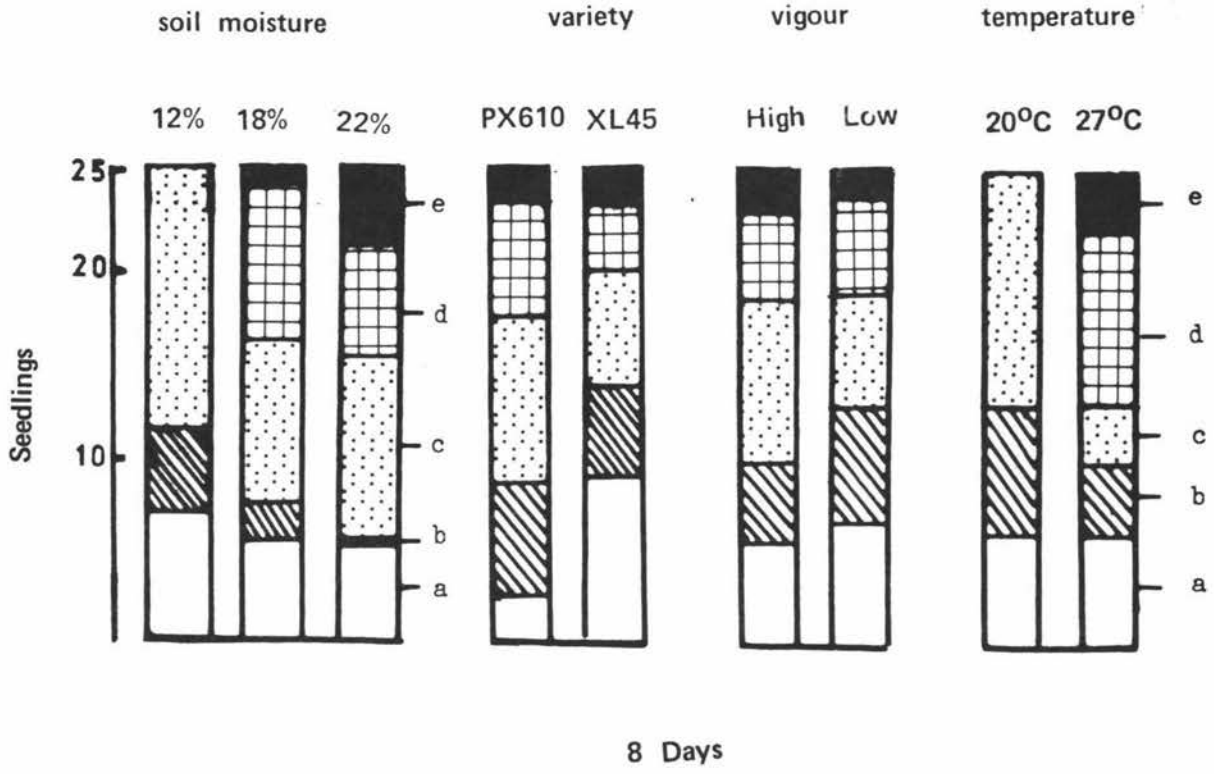


Table 18 b: The effects of temperature, variety and vigour on the shoot length.

Time (days)	Temperature (C^{o})	Shoot Length (cm)	Variety	Shoot Length (cm)	Vigour	Shoot Length (cm)	LSD^{+} 5%
3	20	.19	PX610	.77	High	.75	.07
	27	1.15	XL45	.56	Low	.53	
5	20	1.27	PX610	4.54	High	4.22	.28
	27	7.33	XL45	3.54	Low	3.86	
8	20	5.33	PX610	11.39	High	10.66	.61
	27	14.20	XL45	8.34	Low	9.08	
14	20	16.66	PX610	25.30	High	23.98	1.14
	27	27.07	XL45	17.31	Low	20.06	

LSD^{+} 5% for comparison between temperatures, varieties, and vigour within a date of sampling.

FIG. 16 EFFECT OF MOISTURE AND TEMPERATURE ON SHOOT LENGTH

a = O, b = >O–3, c = 3–10, d = 10–15, e = 15–20 cms

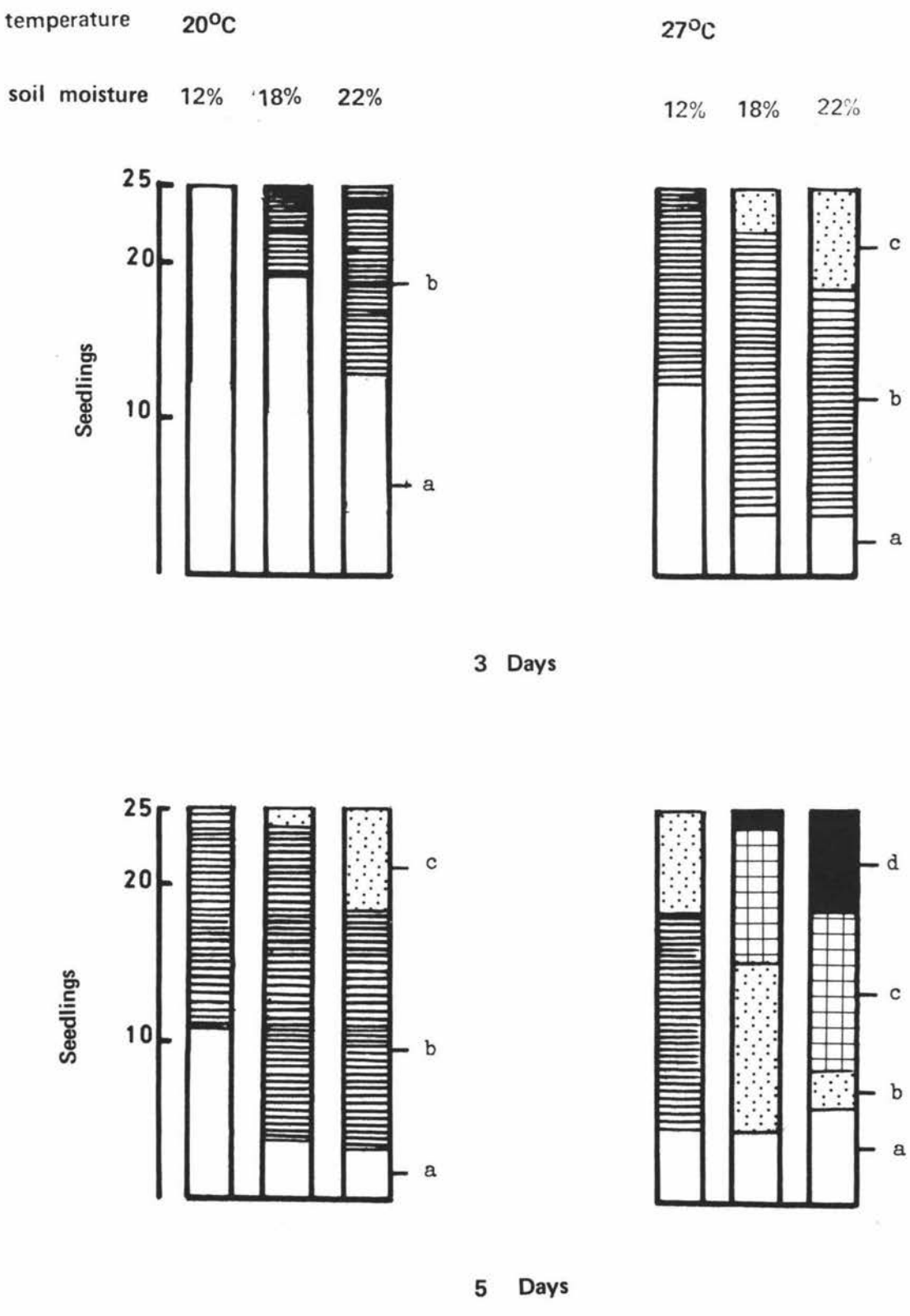
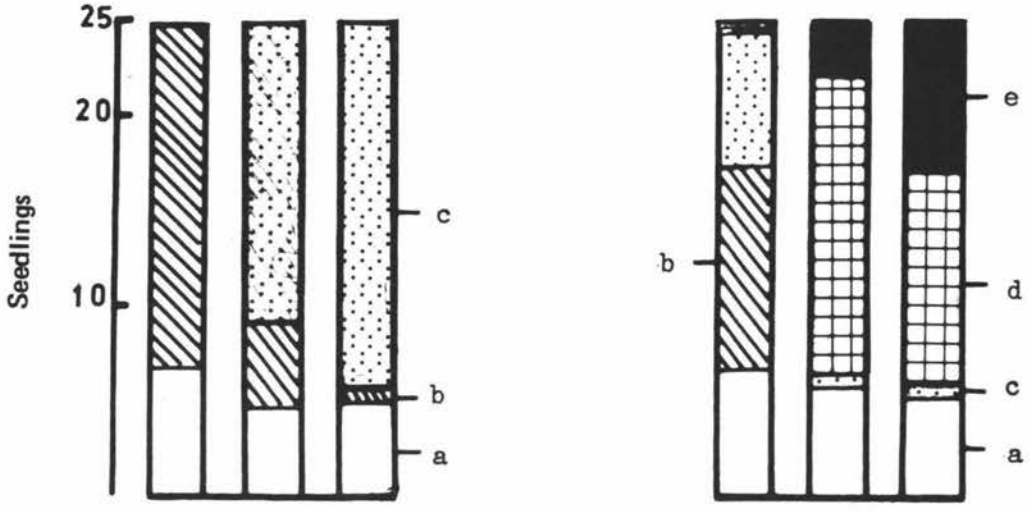


FIG. 16 Continued

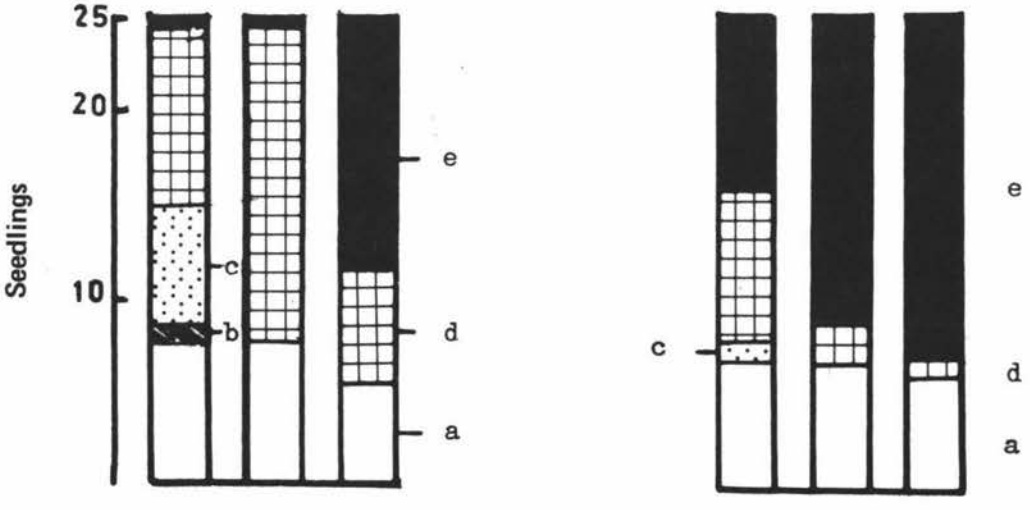
a = O, b = >O–5, c = 5–15, d = 15–30, e = >30

temperature 20°C 27°C

Soil Moistures 12% 18% 22% 12% 18% 22%



8 Days



14 Days

The analysis of variance in Appendix 26 presents the various treatment interactions recorded. The example of these interactions as recorded on the 5th day is shown in Table 19.

Table 19: The significant interaction effects of treatments on average shoot length of seedlings at five days.

Variables	Shoot length (cm)			LSD 5%
	Soil Moisture			
Temperature (C^{o})	12%	18%	22%	
20	.23	1.14	2.45	
27	2.06	8.24	10.16	.49
Variety				
PX610	1.15	5.00	7.46	
XL45	1.11	4.34	5.15	

The effect of the higher temperature on shoot length showed a much greater increase at 12% soil moisture than 18% or 22% moisture although absolute lengths were greater in the latter treatment.

The variety PX610 has significantly higher shoot length than XL45 at 22% and 18% but not at 12% soil moisture level.

A more detailed picture of these moisture and temperatures effects on shoot length is presented in Figure 16.

3.3 DISCUSSION

The results of the laboratory experiment will be discussed in the following order, effects of moisture, temperature, variety and vigour on imbibition, growth of root and shoot, utilisation of the endosperm, seedling emergence and speed of emergence.

3.3.1 Soil mosture - Increased soil moisture level was associated with increased rates of seed imbibition, higher rates of endosperm utilisation and consequently with longer root and shoot lengths after germination. As a result under high moisture conditions, greater emergence and faster speed of emergence of seedlings was obtained.

Up till 36 hours after sowing there was no difference in soil moisture absorbed by seed at 18% or 22% soil moisture levels (S.M.L.) but these levels being greater than that absorbed by seed at 12% S.M.L. After 48 hours more moisture was absorbed by the seed at 22% than 18% and 12% S.M.L. This shows that at the earlier stages seed absorbed water more easily at S.M.L. 18% and above. If the S.M.L. was maintained, similar final seed moisture could be expected from both 18% and 22%.

Germination may have started soon after 24 hours from sowing as found by Toole (1956), particularly at 18% and 22% S.M.L. since at the first observation done at 36 hours, some roots were found to be 1 - 2 cm long.

Longer roots were found at 22% and 18% than at 12% S.M.L. (Table 16 a) at 36 hours. This may have been due to seed sown at higher S.M.L. reaching the minimum seed moisture for germination of 46% (Hunter and Erickson 1952) earlier than at 12%. Therefore longer roots were the consequence of higher S.M.L. The cause of slower absorption may be due to the effect of greater osmotic pressure at low S.M.L. of 12%. Parmar and Moore (1966) and Uhvits (1946) found a decrease in the rate of germination as the osmotic pressure of the substrate was increased in alfalfa and maize.

The average length of root and shoot was found to be greater in higher soil moisture conditions. The differences were greater between 12% than between 18% and 22% S.M.L. This may have been due to the slower germination which occurred at lower S.M.L. In other words higher soil moisture hastens germination.

It was also found that a higher germination percentage was reached at 18% and 22% than at 12% S.M.L. possibly due to the greater competition between seeds for water requirement for germination at 12% S.M.L. More uniform germination was also found at 18% and 22% S.M.L. than at 12% (Figures 13 and 15).

The utilisation of the endosperm was also affected by S.M.L. At high soil moisture levels, more endosperm was utilised (Figure 10 a) recorded approximately the 3rd day after planting. Ingle et al (1964) found during the first 3 days insoluble protein disappeared parallel with increases in soluble protein in the endosperm. A decrease from the endosperm was found later (4 - 5 days) with increase of the axis protein. He also found that carbohydrate hydrolysis was not initiated until 23 hours after planting. This could explain why there was no difference during the first 2 days after planting. The initial use of the food reserve for increased respiration and the transfer of the reserve material from the scutellum and endosperm may come from the indigenous substrate in the axis (Ingle et al 1964).

Marked deceases of the endosperm dry matter at later stages may have been due to the growth of seedlings which depends on the amount of hydrolysed reserve. The more moisture imbibed by the seed the greater the amount of food available for the growth of the seedling. Consequently higher soil moisture hastens and increases seedling emergence. About 60% of the seedlings emerged within 7 days at 18% and 22% but less than 20% at 12% S.M.L. (Figure 7 a).

Speed of emergence was twice as high at 22% and 18% than at 12% (Table 3) and that of 22% S.M.L. was about 10% higher than that at 18% S.M.L. Although there was no difference in the final emergence percentage, emergence was greater and probably more uniform in 22% than 18% S.M.L. during the first few days of emergence.

It has been found by many workers that decreased soil moisture delayed emergence and decreased emergence percentages (e.g. Ayer 1952, Hanks 1960, Parker et al 1965). This suggestion is supported by results in the present experiment. However, in contrast, the field experiment failed to show any significant effect from soil condition, which suggests that moisture levels in the field plots must have been adequate for germination.

It is well to remember that high soil moisture in the field experiment did however depress seedling growth temporarily. This was not assessed in the laboratory experiment as the period was too short. However results might well be different between laboratory and field studies owing to the difficulty of simulating soil compaction and aeration conditions of the field in a pot.

3.3.2 Temperature - Temperatures used were 20°C and 27°C. The temperature recorded in the 27°C germinator was ± 0.5°C. The 20°C temperature was in a controlled temperature room and found to be constant.

Some apparently contradictory effects of temperature on the imbibition of seed is found in the literature. Shull (1920, 1924) found no or little influence of temperature on moisture absorption. Mayer and Poljakoff Mayber (1963) concluded that imbibition proceeded more rapidly at higher temperatures.

The present experiment found that the moisture absorption of seed was similar at both 20°C and 27°C during the first 24 hours of imbibition. At later stages (36 and 48 hours) more moisture was absorbed by seeds at 27°C than 20°C and reached 60% and 51% respectively at 48 hours.

As seed absorbs moisture, respiration becomes significantly higher and rises rapidly as absorption of water continues (Stiles 1960). Whether temperature affects the absorption of moisture by seed or not, it does affect seed respiration (Mayer and Poljakoff Mayber 1963 and Stiles 1960).

It was found that in the early stages of absorption, water uptake was not affected by metabolic conditions. This has been shown by work comparing the water uptake of viable and non viable seeds (Atkinson cited by Brown 1965). In this experiment the earlier stage of absorption was not examined. More frequent observations during the very early stages would need to be carried out.

Additional moisture absorbed during the later stages of germination may be caused by faster growth of the embryo. Consequently more moisture may be required for hydrolysing seed reserves.

The present experiment found the emergence of the root was hastened at 27°C. No root was observed after 48 hours at 20°C whereas roots were found at 27°C 36 hours after planting (Figure 14).

Greater average root and shoot growth occurred at 27°C than at 20°C. Whether temperature affected the rate of increase in root length was not studied in this experiment. Highkin and Lang (1966) and Laude and Cobb (1969) found in peas and barley that lower height of seedling resulted from lower temperature.

Differences in utilisation of the endosperm at 20°C and 27°C did not show up until 5 days after planting. As no observation was made between 3 to 5 days, the difference may have occurred earlier. Nevertheless a greater rate of reduction in endosperm dry matter was found at 27°C than at 20°C (Figure 10 b). This was obviously due to greater growth at the higher temperature. It was found that less than 30% of the endosperm was left on the 14th day at 27°C and about 45% left at 20°C.

High temperature hastened germination. This consequently hastened emergence of seedlings, increased the emergence percentage and also increased the speed of germination.

The speed of emergence at 27°C was twice as fast as that at 20°C (Table 13) and a shorter period of emergence was required at the higher temperature (Figure 7 b). This result supports the findings of Aikman(1933), Alessi and Power (1971). Alessi and Power found a reduction of 80% of time in the emergence of corn as the temperature increased from 13.3°C to 26.7°C.

The effect of temperature was found to be greater at the lower soil moisture (12%). At this S.M.L. emergence began earlier, a higher percentage of seedlings emerged and emergence was completed in a shorter time at 27°C. A similar effect was also found in shoot growth after germination. At this low soil moisture level, shoot emergence was observed 3 days after planting at 27°C but 5 days after planting at 20°C (Figure 16).

Pollock (1972) concluded that the major effect of temperature was on the time germination began. As temperature increased so did the rate of germination. Consequently greater advancement of growth occurred under higher temperature conditions.

3.3.3 Variety - Laboratory results supported those obtained in the field, PX610 being superior to XL45 in performance.

It was found that more moisture was absorbed by XL45 than

PX610 during the first 24 hours (35% and 30% respectively). The seed moisture reached a higher final content in XL45 at 48 hours compared with PX610. Fayustov (1970) in maize found more intensive water uptake which reached a higher level in smaller than larger seeded varieties. This may be the explanation in the present study since XL45 was smaller than the seed of PX610.

XL45 had greater root growth than PX610 during the early stages. Since XL45 absorbed moisture faster one would have expected the germination of XL45 to begin earlier than in PX610. However PX610 showed a greater ability for germination and seedling growth. Therefore soon after the beginning of root emergence greater root length was obtained in PX610 and maintained right through the first 5 days.

The shoot length was obviously higher and a greater rate of increase in the length of both root and shoot occurred in PX610 than in XL45 (Tables 16 b and 18 b). Both lots of XL45 used were found to have a large amount of non-germinated seeds (Figure 15). In other words XL45 had a lower vigour than PX610.

As there was no aeration problem in the soil used in the laboratory experiment, the response of the growth of shoots of PX610 was geater than that of XL45 as soil moisture content was increased. However under drier conditions of 12% S.M.L. the superiority of PX610 over that of XL45 disappeared (Table 19).

By comparison with XL45, PX610 showed a higher rate of utilisation of endosperm especially after the root and shoot had emerged from the seed (after 3 days Figure 10 c). Consequently PX610 had a greater percentage seedling emergence and greater emergence speed. Under low S.M.L. XL45 had the ability to emerge faster at the beginning which may have reflected its initial effect of greater ability to imbibe water than PX610. Once PX610 had started to emerge, even at low soil moisture levels, it increased faster with a higher emergence of seedlings than XL45 and resulted in no difference in emergence speed at 12% S.M.L.

In other words PX610 had a higher growth rate and more conformity in germination than XL45 but XL45 had a greater ability to imbibe moisture because of being smaller than PX610. With the higher growth rate of the embryo and seedling a greater amount of the endosperm was utilised in PX610. Accordingly PX610 showed a greater emergence

speed and higher seedling emergence than XL45 but under low moisture both varieties behaved similarly.

It is very interesting to see similar variations in seedling emergence and root and shoot length, these variations being smaller as the length and emergence increased (Appendix 15, Tables 16 a and 19 a).

3.3.4 Seed vigour - In the laboratory experiment with constant temperatures and moistures it was found that high vigour seeds performed better than low vigour seeds.

At imbibition, low vigour seeds showed a greater ability to absorb moisture than high vigour seeds, especially during the first 24 hours after planting. However high vigour seed held greater amounts of water at later stages of imbibition.

Imbibition is a physical process which is related to the properties of colloids and it is not related to viability (Mayer and Poljakoff Mayber 1963, and Brown 1965). The reason for this has not been fully explained. However Andrew (1952) found that in corn seed a comparatively rapid increase in kernel volume occurred in both higher germinating and low germinating lines.

Similar absorption rates occurred in high and low vigour seed in XL45. However, during the early stages of imbibition low vigour seed of PX610 absorbed more moisture than high vigour seed. This may be due to only small differences in vigour of the XL45 between lines used but larger differences occurred between lines of PX610.

It was found there was greater growth from high vigour seed compared with low vigour seed. Germination began earlier resulting in greater root and shoot length (Figures 13 and 15).

High vigour seed did not show faster emergence in the laboratory experiment until after 7 days when greater emergence was obtained from higher vigour seed (Figure 7 d). The speed of emergence was higher (10%) in high - than low - vigour seeds. This may be due to increased emergence during the later stages of emergence.

The concept of emergence speed used in this experiment was adapted from Timpson (1965) by using the average of the accumulated emergence until emergence was completed. The relative percentage obtained is very useful in comparing difference seedlots.

The present experiment resulted in a 10% increase in germination between high and low vigour lines and a 10% higher germination of PX610 over XL45 lines of the same vigour status.

The disadvantage of this method using accumulated totals is the time taken. It can be many days before emergence is complete dependent on factors such as moisture and temperature.

From this we can see that speed of emergence gives quite a clear picture of the behaviour of difference seedlots under different conditions. As Heydecker (1962) has pointed out a total figure of this type helps to offset the effects of changing environmental conditions. However Verhey (1960) concluded that high energy points to first quality seed, but the reverse it not necessarily true.

It was shown generally that a greater rate of utilisation of the endosperm occurred in high - than low - vigour seed. In PX610 this effect did not appear till approximately 50% of the seedlings had emerged. There was no such difference between high and low vigour lots of XL45 in this respect.

Possibly the small difference in the interim germination between the two lines of XL45 used indicates the difference in vigour of XL45. This particular variety had a relatively low total germination. This relatively small difference in vigour of the XL45 lines, compared with the PX610 lines, established under control conditions may have accounted for the lack of difference recorded in this variety in the field. At the same time it does suggest that differences in vigour determined under laboratory conditions may well have to be considerable to have any meaning in the field situation.

4. CONCLUSION

In the present experiment, although seedling emergence was slightly higher under normal field conditions, it was not seriously limited by sub-optimal conditions of crusted and wet soils. However after two weeks there was a reduction of growth in crusted and wet soil with lower leaf area, shoot dry matter, height and root/shoot ratio. Growth was seriously reduced under wet soil conditions. This may have been due to poor soil aeration. Four weeks after planting growth was similar in all soil conditions due probably to improvement in soil moisture conditions in the crusted and control plots and better aeration in the wet soil.

Under laboratory conditions with increasing soil moisture and temperature germination began earlier and there was an increase in the rate of seedling emergence and seedling growth. Greater speed of germination was obtained at the higher temperature and at higher moisture (18% and above). At higher temperature and higher soil moisture levels more rapid germination and growth occurred. Such conditions also promoted more rapid endosperm utilisation.

Variety PX610 was superior to XL45 in both seedling emergence and growth. This may be because of genetically higher vigour. The laboratory experiment also showed that PX610 had greater ability to germinate, emerge and had a higher speed of emergence and growth of roots and shoots which resulted in greater ability to utilise the endosperm than XL45. The possibility of poorer environmental and post-harvest handling conditions causing lower vigour in XL45 cannot be overlooked.

In the laboratory experiment slightly higher rates of emergence and emergence percentages were found in high - than low - vigour seeds. However there was no difference between the two vigour levels under field conditions, particularly in XL45. The differences shown in the laboratory experiment may be due to greater control of soil moisture and temperature. It may also mean that the difference in interim germination percentages used to differentiate the high and low vigour lots were not great enough to show up under field conditions. Apparently the environmental conditions in the field were capable of masking or cancelling out differences in seed vigour established under the controlled conditions in the laboratory. The results of this experiment under the so-called good conditions that existed in this

field study would question the value of the technique used to establish differences in seed vigour and to reflect their "field vigour" at least under favourable conditions.

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Appendix 1 - Schedule of Events.

Days from sowing	Date	Event
	15.9.71	Plot ploughed
	22.9.71	Discing
	6.10.71	Measured soil moisture at field capacity.
	15.10.71	1st Rotary Hoeing for the crusted plots.
	19.10.71	Applied lime at ½ ton/acre.
	26.10.71	2nd Rotary hoeing for crusted plots.
	10.11.71	3rd Rotary hoeing for crusted plots.
	17.11.71	4th Rotary hoeing for crusted plots.
	22.11.71	5th Rotary hoeing for crusted plots.
	2.12.71	Applied fertiliser (10:18:8 NPK) 200 lbs/acre.
	4.12.71	All plots were rotary hoed.
0	6.12.71	Sowed crop.
1	7.12.71	Irrigated the crusted and wet plots, covered crusted plots with polythene paper.
2	8.12.71	Irrigated wet plot with soak hoses (till the surface was submerged).
3	9.12.71	Irrigated wet plots, and sprayed with Triazone 4 lb/acre to the wet and control plots.
4	10.12.71	Irrigated wet plots.
5	11.12.71	Irrigated wet plots.
6	12.12.71	Irrigated wet plots and emergence of seedlings was observed.
7	13.12.71	Irrigated wet plots.
8	14.12.71	Irrigated wet plots. Emergence of seedlings was recorded.
9	15.12.71	No irrigation
10	16.12.71	Seedling emergence was completed.
11	17.12.71	Irrigated wet plots.
12	18.12.71	Irrigated wet plots.
13	19.12.71	First sampling and stopped irrigation and uncovered the crusted plots.
27	3.1.72	2nd sampling.

Appendix 2 - Soil Moisture.

Seedbed \ Days	6	7	8	9	10	11	12	13	14	16	18	20	22	24	26
Crusted	9.4	9.4	7.8	7.49	7.34	7.2	7.0	-	7.6	7.31	15.25	14.1	13.8	11.9	10.5
Wet	20.1	19.8	22.1	21.4	21.0	21.5	19.8	-	16.64	14.42	15.21	15.0	14.0	12.1	11.2
Control	10.6	9.8	9.0	8.7	10.2	10.4	9.5	-	8.1	7.55	14.3	13.8	13.0	13.3	10.0

Appendix 3 - Average soil temperature at 2" depth °C

Seedbed \ Days	1	2	3	4	5	6	7	8	9	10	11	12	13	
Crusted	15.0	16.0	12.2	13.8	16.2	15.8	15.8	18.0	18.8	19.3	19.5	19.25	20.0	
Wet	15.0	16.4	12.0	12.8	15.5	14.3	14.0	16.3	17.0	17.4	18.5	18.35	18.5	7 a.m.
Control	15.1	16.5	12.4	14.0	16.5	15.8	15.3	17.8	19.0	18.8	20.5	20.3	21.0	
							10 a.m.							
Crusted	17.8	17.3	18.6	20.3	18.8	19.8	21.3	23.9	23.5	24.3	25.3	24.8	23.8	
Wet	19.8	17.5	20.0	20.7	18.5	19.5	21.5	22.5	22.5	23.3	24.5	23.5	21.8	10 a.m.
Control	19.3	18.5	19.0	20.0	19.5	19.8	22.3	23.3	23.3	25.5	25.6	24.8	23.8	
							1 p.m.							
Crusted	20.5	18.8	24.0	24.5	25.0	25.3	28.0	30.3	28.3	30.5	31.0	31.3	27.0	
Wet	23.3	18.5	26.0	24.3	23.8	23.3	26.5	27.5	26.0	26.8	26.8	26.5	24.5	1 p.m.
Control	22.5	19.8	25.5	25.0	25.0	25.3	27.8	29.8	27.5	29.5	30.0	29.5	28.5	
							4 p.m.							
Crusted	19.5	17.5	24.5	15.0	26.5	25.8	28.3	30.0	28.8	32.0	32.5	32.0	28.5	
Wet	19.8	17.5	24.3	23.3	23.8	23.0	25.0	26.3	24.8	26.0	26.6	26.0	23.8	4 p.m.
Control	21.0	19.5	25.0	25.3	26.8	25.8	28.0	29.5	28.5	30.8	31.3	30.5	29.0	

Appendix 4 - Analysis of variance of soil aggregate stability (arcsin transformation).

Source of variation	df	M.S.
Replication	3	19.50 NS
Treatment	3	191.32^{++}
Error	9	13.50
CV%		10.07

Appendix 5 - Analysis of variance of soil bulk density.

Source of variation	df	M.S.
Replication	3	.009 NS
Treatment	2	.568^{++}
Error	6	.005
CV%		7.19

Appendix 6 - Days of first seedling emergence after planting.

Variety		PX610		XL45	
Seedbed condition	Replication	Low Vigour	High Vigour	Low Vigour	High Vigour
Crusted	1	7	7	7	7
	2	7	7	7	7
	3	7	7	7	7
	4	7	7	7	7
Wet	1	7	6	6	6
	2	8	8	7	7
	3	8	8	8	8
	4	7	7	7	7
Control	1	6	6	6	6
	2	7	7	7	7
	3	7	7	7	7
	4	7	7	7	7

Appendix 7 - Analysis of variance of seedling emergence in the field

Source of variation	df	8 days, M.S.		9 days, M.S.		12 days (total) M.S.	
Replication	3	90.56	NS	90.73	NS	67.87	NS
Soil	2	351.57	NS	119.80	NS	99.63	NS
Error (a)	6	73.22		29.49		23.96	
CV%		14.1		8.6		7.53	
Variety	1	3282.5284^{++}		2935.78^{++}		2233.00^{++}	
Var x Soil	2	63.42	NS	12.86	NS	5.28	NS
Error (b)	9	139.23		64.72		35.90	
CV%		19.5		12.8		9.21	
Vigour	1	135.95^{+}		104.22	NS	37.86	NS
Vig x Soil	1	89.65	NS	56.11	NS	80.78	NS
Vig x Var	2	42.06	NS	81.88	NS	151.48^{+}	
Vig x Var x Soil	2	26.49	NS	.22	NS	2.45	NS
Error (c)	18	22.55		24.47		27.62	
CV%		7.9		7.9		8.08	

Appendix 8 - Seedling emergence in the field (Arcsin transformation).

Time (days)	Variety	Seedling emergence	LSD 5%	Vigour	Seedling Emergence	LSD 5%
8	PX610	68.76 (87%)	7.7	High	62.77 (78%)	2.88
	XL45	52.22 (62%)		Low	58.8 (73%)	
9	PX610	70.83 (89%)	5.52	High	64.49 (82%)	
	XL45	55.52 (68%)		Low	61.54 (77%)	
11 (total)	PX610	71.85 (90%)	3.91	High	65.92 (83%)	
	XL45	58.21 (72%)		Low	64.14 (81%)	

Appendix 9 - Analysis of variance of shoot dry weight.

Source of variation	df	M.S. 2 weeks		M.S. 4 weeks	
Replication	3	.0028	NS	.3666	NS
Soil	2	.0488^{++}		.5828	
Error (a)	6	.0009		.3267	
CV%		19.31		31.16	
Variety	1	.0437^{++}		3.3054^{++}	
Var x Soil	2	.0031	NS	1.1071	
Error (b)	9	.0013		.1512	
CV%		17.21		21.20	
Vigour	1	.0006	NS	.0024	NS
Vig x Var	1	.0001	NS	.0875	NS
Vig x Soil	2	.0008	NS	.0130	NS
Vig x Var x Soil	2	.0008	NS	.4477^{+}	
Error (c)	18	.0006		.1258	
CV%		11.69		19.33	

Appendix 10 - Analysis of variance of leaf area per plant.

Source of variation	df	M.S. 2 weeks		M.S. 4 weeks	
Replication	3	376.22	NS	9,923.25	NS
Soil	2	1,301.08^{+}		13,103.15	NS
Error (a)	6	243.34		3,463.81	
CV%		20.82		24.9	
Variety	1	2,794.41^{++}		51,961.73	
Var x Soil	2	200.89	NS	14,416.82	NS
Error (b)	9	228.01		3,591.23	
CV%		20.15		25.9	
Vigour	1	192.32	NS	2,709.28	NS
Vig x Var	1	90.27	NS	947.12	NS
Vig x Soil	2	293.83	NS	4.37	NS
Vig x Var x Soil	2	77.60	NS	5,725.83	NS
Error (c)	18	89.19		3,001.07	
CV%		12.60		24.2	

Appendix 11 - Analysis of variance of height of seedlings.

Source of variation	df	M.S. 2 weeks		M.S. 4 weeks	
Replication	3	6.11	NS	3.47	NS
Soil	2	113.75^{++}		14.28	NS
Error (a)	6	11.21		25.53	
CV%		19.64		13.19	
Variety	1	93.97^{++}		574.77^{++}	
Var x Soil	2	20.34	NS	14.3	NS
Error (b)	9	7.66		9.75	
CV%		16.23		8.20	
Vigour	1	2.08	NS	3.50	NS
Vig x Var	1	3.44	NS	5.16	NS
Vig x Soil	2	.75	NS	2.05	NS
Vig x Var x Soil	2	1.14	NS	14.64^{+}	
Error (c)	18	1.27		2.88	
CV%		6.61		4.5	

Appendix 12 - Analysis of variance of root/shoot ratio.

Source of variation	df	M.S. 2 weeks		M.S. 4 weeks	
Replication	3	.0276	NS	.0016	NS
Soil	2	.1146^{++}		.0389^{++}	
Error (a)	6	.0076		.0023	
CV%		11.55		12.48	
Variety	1	.0591		.0243	
Var x Soil	2	.0402	NS	.0145^{+}	
Error (b)	9	.0099		.0025	
CV%		13.64		13.02	
Vigour	1	.0320	NS	.0002	NS
Vig x Var	1	.0109	NS	.007	NS
Vig x Soil	2	.0224	NS	.0028	NS
Vig x Var x Soil	2	.0022	NS	.009	NS
Error (c)	18	.0297	NS	.0026	NS
CV%		23.67		13.27	

Appendix 13 - Analysis of variance of imbibition.

Source of variation	df	24 hours M.S.	36 hours M.S.	48 hours M.S.
Moisture (M)	2	70.01^{++}	112.24^{++}	337.18^{++}
Vigour (V)	1	67.21^{++}	38.37^{++}	61.96^{++}
Variety (W)	1	153.89^{++}	107.93^{++}	45.08^{++}
Temperature (T)	1	8.89 NS	100.00^{++}	886.15^{++}
Interactions -				
M x V	2	8.09 NS	25.53^{++}	2.79 NS
M x W	2	5.51 NS	18.27^{++}	4.97 NS
M x T	2	6.28 NS	21.69^{++}	197.39^{++}
V x W	1	20.41^{++}	124.68^{++}	35.12^{++}
V x T	1	8.05 NS	2.11 NS	70.74^{++}
W x T	1	1.46 NS	2.19 NS	5.83 NS
M x V x W	2	3.27 NS	13.98^{++}	1.11 NS
M x V x T	2	10.40^{+}	11.00^{++}	2.46 NS
M x W x T	2	2.60 NS	11.40^{++}	23.76^{++}
V x W x T	1	7.27 NS	9.82^{+}	9.98^{+}
M x V x W x T	2	7.20 NS	1.21 NS	19.13^{++}
Error	115	2.95	2.08	2.48
CV%		4.07	3.19	3.27

Appendix 14 - Analysis of variance of emergence of seedling. (Arcsin transformation)

Source of variation	df	Day 5 M.S.	Day 7 M.S.	Day 9 M.S.	Day 12 M.S.	Day 14 M.S.	Day 17 M.S.	Day 19 M.S.	Speed of germination
Moisture (M)	2	3876.12^{++}	12218.07^{++}	9599.71^{++}	4023.38^{++}	1987.95^{++}	975.25^{++}	868.45^{++}	26110.31^{++}
Vigour (V)	1	481.45NS	1203.01^{++}	452.84^{+}	746.69^{++}	192.02NS	548.55^{++}	694.63^{++}	1276.30^{++}
Variety (W)	1	120.86NS	2037.64^{++}	2444.25^{++}	4702.36^{++}	2929.55^{++}	5961.68^{++}	6971.09^{++}	8048.33^{++}
Temperature (T)	1	36878.82^{++}	15226.90^{++}	4958.71^{++}	2545.69^{++}	2842.82^{++}	673.60^{++}	387.01^{++}	48217.48^{++}
Interactions -									
M x V	2	240.68NS	28.83NS	181.49NS	41.18NS	235.31^{+}	22.82NS	40.59NS	32.30NS
M x W	2	512.19^{+}	1488.81^{++}	1001.36^{++}	986.12^{++}	480.27^{++}	355.26^{++}	306.21^{++}	3176.09^{++}
M x T	2	2484.01^{++}	2352.36^{++}	3534.54^{++}	1366.18^{++}	374.15^{++}	121.77NS	96.53NS	578.45^{+}
V x W	1	0.26NS	533.56^{++}	163.07NS	355.94^{+}	43.81NS	393.52^{+}	545.77^{++}	493.18NS
V x T	1	344.52NS	139.16NS	170.60NS	28.14NS	31.26NS	7.34NS	38.87NS	186.18NS
W x T	1	79.85NS	71.69NS	76.31NS	0.23NS	65.39NS	2.16NS	53.62NS	0.15NS
M x V x W	2	256.44NS	49.55NS	52.51NS	3.53NS	44.44NS		14.58NS	35.27NS
M x V x T	2	347.50NS	86.42NS	45.05NS	140.91NS	162.15NS	191.46NS	120.81NS	53.85NS
M x W x T	2	470.66^{+}	148.85NS	59.92NS	37.73NS	243.66^{+}	19.41NS	56.14NS	164.80NS
V x W x T	1	248.37NS	35.38NS	112.10NS	13.48NS	253.99NS	2.12NS	2.18NS	65.51NS
M x V x W x T	2	12.51NS	31.71NS	263.05NS	0.45NS	77.57NS	91.61NS	50.67NS	122.35NS
Error	46	123.62	62.93	104.69	61.60	66.16	61.91	41.35	132.97
CV%		44.35	16.56	18.10	12.40	12.46	11.78	9.51	11.39

Appendix 15 - Soil moistures and seedling emergence

Time (days)	Seedling emergence			LSD 5%
	12%	18%	22%	
5	14.25+ (6%)++	28.88 (23%)	35.44 (34%)	6.46
7	22.42 (15%)	55.41 (68%)	69.57 (88%)	4.01
9	33.72 (31%)	60.99 (77%)	71.10 (90%)	5.95
12	48.39 (56%)	69.48 (88%)	71.92 (90%)	4.56
14	54.83 (67%)	70.70 (88%)	71.92 (90%)	4.76
17	59.76 (75%)	70.27 (89%)	71.92 (90%)	4.57
19	59.97 (75%)	70.27 (89%)	71.92 (90%)	3.73

+ Arcsin value

( )++ equivalent percentage to the arcsin value.

Appendix 16 - Seedling emergence at 20°C and 27°C.

Time (days)	Seedling emergence		LSD 5%
	20°C	27°C	
5	2.44+ (.18%)++	49.94 (59%)	5.28
7	34.84 (33%)	63.43 (80%)	3.77
9	48.22 (56%)	67.32 (85%)	4.86
12	57.31 (71%)	69.22 (87%)	3.73
14	58.50 (73%)	69.99 (88%)	3.86
17	61.96 (78%)	69.99 (88%)	3.73
19	61.96 (78%)	69.99 (88%)	3.05

+ Arcsin value

( )++ equivalent percentage to the arcsin value.

Appendix 17 - Seedling emergence of varieties PX610 and XL45.

Time (days)	Emergence		LSD 5%
	PX610	XL45	
5	26.77[+] (24%)[++]	25.58 (23%)	NS
7	53.77 (65%)	44.49 (49%)	3.77
9	59.85 (75%)	50.70 (60%)	4.86
12	71.34 (90%)	55.19 (67%)	3.73
14	71.66 (90%)	58.40 (73%)	3.86
17	76.80 (95%)	58.80 (73%)	3.76
19	77.50 (95%)	58.90 (73%)	3.05

[+] Arcsin value

( )[++] equivalent percentage to the arcsin value.

Appendix 18 - Seedling emergence of high and low vigour.

Time (days)	Emergence		LSD 5%
	High Vigour	Low Vigour	
5	33.21[+] (30%)[++]	34.45 (32%)	NS
7	53.47 (65%)	44.80 (50%)	3.77
9	56.53 (70%)	54.01 (66%)	4.86
12	61.03 (75%)	57.02 (71%)	3.73
14	64.16 (81%)	58.69 (73%)	NS
17	70.05 (88%)	64.17 (81%)	3.76
19	70.34 (90%)	64.17 (81%)	3.05

[+] Arcsin value

( )[++] equivalent percentage to the arcsin value.

Appendix 19 - Effects of soil moisture on the emergence of PX610 and XL45

Days	Varieties	Soil moisture			LSD 5%
		12%	18%	22%	
5	PX610	8.07[+] (2%)[++]	32.88 (30%)	39.36 (40%)	9.14
	XL45	20.44 (12%)	24.80 (18%)	31.52 (27%)	
7	PX610	18.30 (10%)	62.48 (79%)	80.54 (97%)	6.52
	XL45	26.54 (20%)	48.35 (56%)	58.60 (73%)	
9	PX610	33.17 (30%)	69.12 (87%)	83.46 (99%)	4.41
	XL45	34.27 (32%)	54.03 (66%)	58.73 (73%)	
12	PX610	49.08 (57%)	80.87 (98%)	89.06 (99%)	6.45
	XL45	47.70 (55%)	58.05 (72%)	59.79 (75%)	
14	PX610	57.72 (72%)	81.82 (98%)	84.06 (99%)	6.69
	XL45	51.93 (62%)	58.56 (73%)	59.79 (75%)	
17	PX610	64.52 (81%)	81.82 (98%)	84.06 (99%)	6.47
	XL45	54.99 (67%)	58.56 (73%)	59.79 (75%)	
19	PX610	66.45 (84%)	81.82 (98%)	84.06 (99%)	5.29
	XL45	54.99 (67%)	58.56 (73%)	59.69 (75%)	

[+] Arcsin value

( )[++] equivalent percentage to the arcsin value.

Appendix 20 - Significant effect of soil moisture and temperature on emergence of seedlings.

Days	Temperature	Soil moisture			LSD 5%
		12%	18%	22%	
3	20°C	0 (0%)++	0 (0%)	7.31 (2%)	9.14
	27°C	28.52+ (23%)++	57.75 (72%)	63.57 (80%)	
7	20°C	0 (0%)	58.40 (78%)	66.12 (84%)	6.52
	27°C	44.84 (50%)	67.92 (85%)	73.02 (91%)	
9	20°C	11.43 (4%)	64.08 (81%)	69.16 (87%)	4.41
	27°C	56.01 (69%)	72.42 (91%)	73.03 (92%)	
12	20°C	33.74 (31%)	67.25 (85%)	71.61 (89%)	6.45
	27°C	63.04 (79%)	73.38 (92%)	73.24 (92%)	
14	20°C	44.31 (49%)	67.58 (85%)	71.16 (89%)	6.69
	27°C	65.35 (83%)	74.17 (93%)	73.24 (92%)	
17	20°C	54.15 (66%)	67.58 (85%)	71.16 (89%)	NS
	27°C	65.35 (83%)	74.14 (93%)	74.24 (93%)	
19	20°C	54.58 (66%)	67.58 (85%)	71.16 (89%)	NS
	27°C	65.35 (83%)	74.17 (93%)	74.40 (93%)	

+ Arcsin value

( )++ equivalent percentage to the arcsin value.

Appendix 21 - Analysis of variance of dry matter of seeds after planting. (Arcsin transformation)

Source of variation	df	1st day M.S.	2nd day M.S.	3rd day M.S.	5th day M.S.	8th day M.S.	14th day M.S.
Moisture (M)	2	2.56 NS	10.27^{+}	60.89^{++}	274.86^{++}	824.07^{++}	618.49^{++}
Vigour (V)	1	0.65 NS	0.24 NS	4.19 NS	52.14 NS	239.21^{++}	667.83^{++}
Variety (W)	1	6.36 NS	0.86 NS	17.41^{+}	69.38^{++}	99.98^{++}	203.00^{++}
Temperature (T)	1	35.82^{++}	0.46 NS	7.92 NS	263.68^{++}	2013.47^{++}	2768.99^{++}
Interactions -							
M x V	2	0.59 NS	2.73 NS	2.19 NS	3.51 NS	6.64 NS	33.71 NS
M x W	2	5.52 NS	0.07 NS	3.63 NS	5.21 NS	0.53 NS	2.95 NS
M x T	2	5.25 NS	6.33^{+}	26.35^{++}	30.24^{++}	41.36^{++}	51.93^{++}
V x W	1	2.59 NS	11.73^{++}	17.15^{+}	49.11^{++}	67.83^{++}	105.02^{++}
V x T	1	7.26 NS	1.09 NS	0.09 NS	5.61 NS	20.38^{++}	0.06 NS
W x T	1	2.57 NS	0.08 NS	0.20 NS	0.48 NS	39.81^{++}	4.26 NS
M x V x W	2	3.19 NS	0.28 NS	1.14 NS	7.45 NS	11.26^{+}	4.73 NS
M x V x T	2	5.18 NS	0.81 NS	6.81 NS	6.64 NS	1.26 NS	23.69^{++}
M x W x T	2	9.19^{+}	1.51 NS	14.27^{+}	2.91 NS	8.54^{+}	6.36 NS
V x W x T	1	3.69 NS	0.07 NS	0.35 NS	4.64 NS	2.15 NS	19.23^{+}
M x V x W x T	2	1.89 NS	0.52 NS	2.41 NS	14.40^{+}	8.75^{+}	4.99 NS
Error	115	1.96	1.90	3.19	3.64	2.25	2.92
CV%		2.03	2.02	2.77	3.53	3.00	4.58

Appendix 22 - The significant responses of endosperm dry matter to treatment.

Time (days)	Variable	Dry matter	LSD 5%
1	Soil moisture 12%	68.94[+] (87%)[++]	NS
	18%	68.49 (87%)	
	22%	69.84 (88%)	
2	Soil moisture 12%	68.27 (86%)	.80
	18%	68.37 (86%)	
	22%	67.40 (85%)	
3	Soil moisture 12%	66.12 (84%)	1.04
	18%	64.10 (81%)	
	22%	62.96 (79%)	
5	Soil moisture 12%	61.06 (77%)	1.12
	18%	56.39 (69%)	
	22%	54.49 (66%)	
8	Soil moisture 12%	56.08 (69%)	.87
	18%	49.24 (57%)	
	22%	44.42 (49%)	
14	Soil moisture 12%	42.08 (45%)	1.0
	18%	38.04 (38%)	
	22%	31.91 (28%)	
1	Variety PX610	69.40 (88%)	NS
	XL45	69.13 (87%)	
2	Variety PX610	68.06 (86%)	NS
	XL45	68.00 (86%)	
3	Variety PX610	63.90 (81%)	.95
	XL45	64.89 (82%)	
5	Variety PX610	56.63 (70%)	.91
	XL45	58.30 (72%)	
8	Variety PX610	48.74 (57%)	.71
	XL45	51.09 (61%)	
14	Variety PX610	35.68 (34%)	.82
	XL45	39.01 (40%)	
1	Vigour High	68.93 (87%)	NS
	Low	68.74 (87%)	
2	Vigour High	68.17 (86%)	NS
	Low	68.03 (86%)	

Appendix 22 - continued

Time (days)	Variable	Dry matter	LSD 5%
3	Vigour High Low	64.15 (81%) 64.64 (82%)	NS
5	Vigour High Low	56.46 (70%) 58.17 (92%)	.91
8	Vigour High Low	48.09 (55%) 51.74 (63%)	.71
14	Vigour High Low	34.37 (32%) 40.32 (42%)	.82
1	Temperature 20°C 27°C	68.14 (86%) 69.55 (88%)	.47
2	Temperature 20°C 27°C	68.06 (86%) 67.73 (86%)	NS
3	Temperature 20°C 27°C	64.49 (81%) 64.24 (81%)	NS
5	Temperature 20°C 27°C	59.23 (72%) 55.40 (68%)	.91
8	Temperature 20°C 27°C	55.20 (68%) 44.63 (49%)	.71
14	Temperature 20°C 27°C	43.61 (48%) 31.08 (27%)	.82

+ Arcsin value.

( )++ equivalent percentage of the arcsin value.

Appendix 23 - The dry matter of seed sown on 12%, 18% and 22% soil moisture and at 20°C and 27°C temperature.

Time (days)	Temperature	Moistures						LSD 5%
		12%		18%		22%		
1	20°C	68.08+	(86%)++	68.29	(86%)	68.03	(86%)	NS
	27°C	69.80	(88%)	68.15	(86%)	70.18	(88%)	
2	20°C	68.05	(86%)	68.30	(86%)	67.83	(85%)	1.14
	27°C	68.30	(86%)	68.44	(87%)	66.47	(85%)	
3	20°C	65.25	(83%)	64.99	(82%)	63.23	(87%)	1.46
	27°C	66.99	(85%)	63.97	(81%)	61.77	(78%)	
5	20°C	62.13	(78%)	57.88	(72%)	57.67	(71%)	1.56
	27°C	60.00	(75%)	54.90	(67%)	51.30	(61%)	
8	20°C	59.87	(75%)	55.49	(68%)	50.25	(59%)	1.23
	27°C	52.29	(63%)	42.99	(47%)	38.59	(39%)	
14	20°C	50.79	(60%)	44.57	(47%)	35.48	(34%)	1.42
	27°C	33.37	(30%)	31.51	(27%)	28.34	(23%)	

+ Arcsin value.

( )++ equivalent percentage of the arcsin value.

Appendix 24 - The dry matter of PX610 and XL45 at high and low vigour.

Time (days)	Vigour	Variety				LSD 5%
		PX610		XL45		
1	High	68.44+	(87%)++	69.42	(88%)	NS
	Low	68.63	(87%)	68.85	(87%)	
2	High	67.62	(86%)	68.71	(87%)	.93
	Low	68.36	(86%)	67.70	(86%)	
3	High	63.17	(80%)	65.13	(82%)	1.20
	Low	64.64	(82%)	64.64	(82%)	
5	High	54.66	(86%)	58.27	(72%)	1.28
	Low	58.01	(72%)	58.32	(72%)	
8	High	45.94	(52%)	50.24	(59%)	1.09
	Low	51.53	(61%)	51.95	(62%)	
14	High	31.51	(28%)	37.22	(37%)	1.16
	Low	39.85	(41%)	40.79	(43%)	

+ Arcsin value.

( )++ equivalent percentage of the arcsin value.

Appendix 25 - Analysis of variance of root length

Source of variation	df	Average root length			
		M.S. 36 hours	M.S. 2 days	M.S. 3 days	M.S. 5 days
Moisture (M)	2	0.07^{++}	1.24^{++}	25.19^{++}	48.30^{++}
Vigour (V)	1	0.06^{++}	0.47^{++}	6.43^{++}	16.64^{++}
Variety (W)	1	0.01^{++}	0.001 NS	28.47^{++}	161.87^{++}
Temperature (T)	1	0.56^{++}	8.78^{++}	195.03^{++}	231.26^{++}
M x V	2	0.01^{++}	0.07^{++}	0.34 NS	0.07 NS
M x W	2	0.01 NS	0.22^{++}	3.34^{++}	3.87^{++}
M x T	2	0.07^{++}	1.24^{++}	9.39^{++}	6.11^{++}
V x W	1	0.01^{++}	0.17^{++}	3.30^{++}	11.82^{++}
V x T	1	0.06^{++}	0.47^{++}	2.55^{++}	3.40^{++}
W x T	1	0.01^{++}	0.001 NS	31.52^{++}	31.31^{++}
M x V x W	2	0.001 NS	0.15^{++}	0.04 NS	1.29^{+}
M x V x T	2	0.01^{++}	0.07^{++}	0.84^{++}	1.25^{+}
M x W x T	2	0.001 NS	0.22^{++}	4.03^{++}	0.47 NS
V x W x T	1	0.01^{++}	0.17^{++}	2.11^{++}	0.18 NS
M x V x W x T	2	0.001 NS	0.15^{++}	0.37^{++}	1.00 NS
Error	46	0.001	0.01	0.11	0.33
CV%		33.94	28.77	14.61	9.43

Appendix 26 - Analysis of variance of shoot length at 3, 5, 8 and 14 days after sowing.

Source of variation	df	Average shoot length			
		M.S. 3 days	M.S. 5 days	M.S. 8 days	M.S. 14 days
Moisture (M)	2	5.83^{++}	168.59^{++}	1177.06^{++}	900.01^{++}
Vigour (V)	1	0.86^{++}	2.23^{+}	44.27^{++}	265.03^{++}
Variety (W)	1	0.42^{+}	17.60^{++}	166.04^{++}	754.91^{++}
Temperature IT)	1	20.20^{++}	551.78^{++}	1358.59^{++}	1308.60^{++}
Interactions -					
M x V	2	0.36^{++}	0.36 NS	4.93 NS	12.81 NS
M x W	2	0.22^{++}	8.43^{++}	30.82^{++}	72.71^{++}
M x T	2	3.44^{++}	63.70^{++}	207.49^{++}	34.48^{++}
V x W	1	0.12^{+}	4.02^{++}	1.86 NS	53.14^{++}
V x T	1	0.71^{++}	0.01 NS	9.67^{+}	21.49 NS
W x T	1	0.35^{++}	10.10^{++}	30.21^{++}	21.71 NS
M x V x W	2	0.04 NS	0.52 NS	2.79 NS	4.65 NS
M x V x T	2	0.32^{++}	0.35 NS	3.20 NS	0.93 NS
M x W x T	2	0.22^{++}	5.71^{++}	5.73^{+}	24.45^{+}
V x W x T	1	0.06 NS	0.98 NS	0.80 NS	79.92^{++}
M x V x W x T	2	0.02 NS	0.03 NS	0.49 NS	14.08 NS
Error	46	0.02	0.36	1.67	5.80
CV%		23.38	14.84	13.10	10.96