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**THE EFFECT OF NITROGEN,FUNGICIDE,TIME AND
METHOD OF HARVEST ON SEED QUALITY IN SUPER
SWEETCORN.(*Zea mays* L.) cv.ILLINI GOLD**

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Abstract

Super sweetcorn (*Zea mays* L.) poses problems for seed production, because the high seed sugar levels delay seed drying, which means harvest delays and the encouragement of pathogen invasion. These factors reduce seed quality, particularly germination and vigour. In a field experiment at Massey University in the 1994/95 season, the effects of fungicide application, nitrogen fertiliser application rate and time and method of harvest on seed quality and particularly seed vigour of super sweetcorn cv. Illini Gold were investigated.

The experiment used a randomised split-split plot design with four replicates of each treatment. Individual plot size was 3.25m x 4.75m. Seeds were hand sown on 25 November 1995 at a spacing of 75 cm between rows and 25 cm between seeds within the row. Treatments were nitrogen (0, 100, 200 kg N/ha as urea) applied in three split side dressing (15 days after sowing, 50 days after emergence and 30 days after silking) and a fungicide (Sportak 45 EC, 0 and 37 g a.i./ha) applied at tasselling, again during early cob development, and again at seed physiological maturity. Each treatment was split into six sub-plots for hand and machine (stationary thresher) harvest at 35%, 25% and 15% seed moisture content (SMC). At each harvest, 30 cobs were picked per sub plot and 15 were then hand shelled, while 15 were fed into an Almaco STB stationary thresher running at a speed of 396 rpm. Threshed seeds were then ambient air dried to 12% SMC.

Fungicide application failed to control *Fusarium* spp., and these fungi were recovered from 73-88% of the seeds depending on treatment. Because of this fungal infection, the highest germination recorded was 68% (for hand harvesting at

35%SMC), while the lowest was 48% (for machine harvest at 15% SMC). Abnormal seedlings resulting from *Fusarium* induced lesions averaged 25%, and from 10-15% of seeds were dead. *Fusarium* infection level increased and seed quality decreased as harvest was delayed from 35% SMC to 15% SMC. Seed quality (germination and vigour) was greater for hand harvested seeds than machine harvested seeds, as machine harvesting cracked seeds and lead to physical and physiological damage which nearly doubled the percentage of dead seeds. Seed quality did not differ for harvests at 25 and 35% SMC.

Nitrogen application increased the seed nitrogen content and thousand seed weight significantly, but had no effect on the seed vigour parameters recorded, including conductivity and seedling growth. Accelerated ageing vigour test results were confounded by the presence of *Fusarium* fungi, but whether these pathogens affected conductivity results could not be determined. Because of the effects of the *Fusarium* fungi, the hypothesis that the increasing availability of nitrogen would improve cell membrane integrity and therefore increase seed vigour could not be assessed. Effective control strategies for *Fusarium* spp. must be implemented before this hypothesis can be fairly tested in the future.

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CHAPTER 1 INTRODUCTION

INTRODUCTION

1.1 What is sweetcorn.?

Sweetcorn is an important monocotyledonous vegetable belonging to the family *Gramineae*. Sweetcorn is a type of maize (*Zea mays* L) which differs from other types in that sucrose-starch conversion is inhibited, and as a result the seeds remain with a high sugar content (Ferguson et.al.1978). It is similar to maize (*Zea mays* L.) in terms of its botanical classification, growth and development. Sweetcorn can be distinguished from other corns by its high sugar content when in the milk and early dough stage, and by its wrinkled, translucent grain when dry.

1.2 What is super sweetcorn.?

Super sweetcorn is a type of sweetcorn, which has a shrunken-2 gene (sh-2 gene). The sh-2 gene raises the sucrose content to more than 35% of the dry weight of the seed, which is more than twice that of the su normal (sweetcorn) seeds at harvest. Super sweetcorn (sh-2) differs from the su type in that the sugar content of the sh-2 seeds remain high.

A major problem with the sh-2 types is low germination and poor vigour, which results in poor stand establishment. Because of the mutant's drastic influence on starch synthesis, the seeds were not well suited for survival. Also, the increased sugar level may well render them vulnerable to attack by microorganisms (Marshall, 1987).

1.3 What is the problem with super sweetcorn seed quality.?

The cause of problems related to stand establishment and vigour with super sweetcorn are numerous, and have been documented. These are:

1. The concentrated sucrose solution in the endosperm resists drying (Wilson and Trawatha, 1991) which in turn interferes with the completion of seed maturation (Churchill and Andrew,1983.)

2. As the seeds remain with high moisture and sugar content at harvest, delayed harvesting may occur, making the seeds liable to weather and/or pathogen damage (Mashauri, 1993).

3. If seed is harvested at high moisture content,drying is necessary,and seed

can be subjected to both physical and physiological damage (Herter and Burris,1989) and seed quality reductions.

4 Reduced starch levels in sh-2 seeds may not provide sufficient carbohydrate reserves for optimal emergence and vigorous seedling growth rate (Wann, 1980).

5. Low starch levels result in a severely collapsed endosperm and cracked pericarp and air pockets between the pericarp and aleurone layer (Styer and Cantliffe ,1984).

6. High sugar contents elevate the osmotic potential which may cause cell membrane and pericarp damage (imbibition damage), and a consequent increased leaching of sugars from the seeds. This reduces metabolic energy available for embryo growth during germination, and also stimulates the growth of pathogenic micro-organisms (Headrick,et.al.,1990).

1.4 Other environmental factors affecting the quality of super sweetcorn seed.

They are briefly referred to here, but discussed more fully in the literature review.

1. Fertilizer

There is an hypothesis that the nitrogen content of the seed can affect seed vigour, as nitrogen provides the building blocks for protein synthesis and together with phospholipids develops cell membrane structural integrity which leads to high seed vigour. However, if nitrogen supply is low, then cell membrane structure is inadequate and leads to low seed vigour. Austin (1972) stated that an increase in seed vigour following N application was reported to be correlated with an improvement of seed composition, especially protein content. Schweizer and Ries (1969) found that increasing in seed protein content by N application resulted in increased seed vigour in wheat (*Triticum aestivum* L.) and increased seedling vigour and yield in oats (*Avena sativa* L.). However, there is also evidence to the contrary. Hawthorn and Pollard (1966) reported that in pea (*Pisum sativum* L.), several successive years of nitrogen fertilizer application increased seed scald or bleaching .Disruption of cellular membrane occurs in bleached seed , causing electrolytes to be leached out

during imbibition, and resulting in poor seedling emergence in the field (Maguire et al., 1973). Hadarizadeh and George (1989) found that increasing the nitrogen nutrition supply increased seed dry weight, but reduced seed vigour.

2. *Fusarium* infection of the plant in the field to harvest can lead to:

- reduced germination
- reduced plant emergence of the subsequent crop
- reduced seed quality

Poor germination, establishment problems and below optimal and/or uneven plant populations are features of super sweetcorn (Jovic et al., 1993). The presence of seed- and soil-borne pathogens, particularly *Fusarium* spp., is one of the factors that can affect the emergence and establishment performance of super sweetcorn. (Hampton, et al., 1994).

3. Incorrect time and method of harvest

Traditionally super sweetcorn is machine harvested at 30-35% seed moisture content (SMC). If seed is harvested at higher moisture contents, this can lead to immature seed, bruising, heating damage, and problems during artificial drying

Harvesting at lower SMC can lead to increased weathering damage, mechanical damage (splitting/cracking), and bird damage.

Improper techniques and time and methodology for harvesting, drying, threshing and cleaning can substantially lower the quality of seeds before or after storage. As the seed normally has high moisture and sugar content at harvest, any delay in harvesting can lead to a significant decline in seed quality due to weather and pathogen damage. Because it is harvested at high seed moisture content artificial drying is necessary. This may cause mechanical and drying damage and reduce seed quality, if not done without due care and attention.

1.5 Objective of the study.?

This study was designed to identify and measure the effects of these parameters on seed quality of super sweetcorn. The objective was to examine, the effects of nitrogen fertilizer application rate, *Fusarium* control through foliar fungicide application, and time and method of harvest on seed quality, in particular seed vigour, of super sweetcorn cv. Illini Gold.

CHAPTER 2 REVIEW OF LITERATURE

Review of Literature

2.1. Sweet corn seed production

Sweet corn (*Zea mays* L.) is an important monocotyledonous vegetable belonging to the family Gramineae. It is similar to maize (*Zea mays* L.) in terms of its botanical classification, growth and development. Sweet corn can be distinguished from other corns by its high sugar content when in the milk and early dough stage, and by its wrinkled, translucent grains when dry. It is best adapted to a warm climate, and substantial areas of the crop are grown successfully for processing in New Zealand's North Island (Brooking and McPherson, 1986).

2.1.1 Environmental requirements

Sweetcorn require abundant moisture and moderately high temperature for best growth. The season should be sufficiently long to mature a good crop of seed. In warm seasons (defined as a mean temperature of 20-23°C) sweet corn crops have performed well (Salunkhe, et al.,1987; Wilson, 1991), but in cooler seasons (mean temperature of 15-19°C) a substantial risk of poor yields or crop failure is likely, especially in crops that are planted late. Risk can be minimised by using a combination of early-maturing cultivars and early planting (Wilson and Salinger, 1994). Sweetcorn prefers a soil which is warm, well drained and a friable loam. Optimum soil temperature for germination are 15.5°C-25.0°C, and the optimum pH range is 5.5-6.8 (Anon, 1995). In New Zealand, the area planted in sweet corn totalled 3,655 ha (North Island 2,968 ha.,South Island 686.6 ha.)in 1993 (Anon, 1993), virtually all of this being for processing, not seed.

2.1.2 Sowing time and method

Hardacre et al.(1991) advised that the most desirable sowing time for maize in the Manawatu region is in late October, because soil conditions in early to mid October tend to be wet and cold (10-15°C) depending on the season, which may detrimentally affect plant emergence. For sweetcorn, Anon, (1995) recommended sowing in November and December, as these months usually provide an ideal sowing period for good germination and establishment as soil temperatures are expected to have increased (Hardacre et al.,1991). For production of a seed crop, super sweetcorn requires a fine seedbed with adequate soil moisture, using precision planting with effective seed protectants. The seed should be sown 2.5 to 7.5 cm. deep depending on soil type and soil moisture, at a spacing range of 22-30 cm between plants in the row and 60-90 cm between rows and at a sowing rate of 11-17 kg/ha (Anon, 1995). Faungfupony et al.(1993) reported that in Thailand the best results were generally produced by sowing high vigour seed at 2 seeds/hill and with irrigation.

2.1.3 Plant Population

According to a survey by Lamb (1977), the common plant populations for sweetcorn found in practice ranged from 37,000 to 75,000 plants/ha, representing a spacing range of 22-30 cm between plants in the row and 60-90 cm between rows. However, results from previous plant population density studies conducted by Escasinas (1984) and Shetty (1988) at Massey University (Seed Technology Centre) suggest that sweet corn populations might well be increased, as these authors recorded maximum seed yields at 92,000-109,000 plants/ha. However, the plant

density which produced the highest seed yield did not produce the highest seed quality. Anon (1995) recommended a population of 60,000 plants/ha for commercial sweetcorn while Brooking and McPherson (1986) recommended that sweetcorn plant densities in Manawatu should be 50-55,000 plants/ha.

2.1.4 Cultivars

Sweetcorn (*Zea mays* var *Saccharata*) is a selection of maize incorporating a "sweetness" gene which makes it particularly desirable as a fresh vegetable. Early maturing, high sugar hybrid cultivars have been bred to meet a heavy demand for the fresh vegetable market (Shetty, 1988). Cultivars of sweetcorn in New Zealand are as follows (Ballinger, 1993): Champagne Gold, Early Miracle, Golden Cross Bantam, Honey' n Pearl, Honey Sweet, Lightning Gold, Miracle Hybrid, Sno Sweet, Sugar Loaf, Sweet Perfection. Anon (1995) sold Golden Cross Bantam, NK 195, NK 965 and Nucross hybrid. Super sweetcorn (sh-2) cultivars available include Illini Gold and Jubilee.

Cultivars are commonly described by the "average number of days" taken to mature from sowing. The actual time taken to maturity will depend on the particular locality, the time of the season, and local climate, although the relative harvesting dates between cultivars remain about the same as indicated under normal conditions. Early crops take longer to mature due to lower temperatures. Expected days to maturity are from 120-140 days. December planted crops can be expected to mature in 70-90 days. Brooking and McPherson (1986) stated that for the Manawatu, cultivar maturity (days from sowing to 72% kernel moisture) ranged from 115 to 141 days.

2.1.5 Seed maturation

At the end of the food reserve accumulation stage, the seed reaches mass maturity. The inner cell of the endosperm are generally dead tissue, packed solidly with starch such that any surviving cytoplasm is very distorted and does not survive the subsequent desiccation (Olsen et al.,1995). In the aleurone layer cell processes related to desiccation protection similar to that of the embryo must be assumed to take place (Bratels et al.,1988), enabling the cells to survive seed desiccation damage. In maize, the seed is isolated from the maternal plant tissue by the formation of a black cell layer (Daynard and Duncan,1969). Wilson and Trawatha (1991) demonstrated that in sweetcorn, moisture loss declined linearly with maturity. They suggested that drying characteristics of sh-2 kernels are possibly different from that of starchy maize, and that the concentrated sucrose solution in the sweetcorn endosperm resisted drying. The sh-2 genes incorporated in sweetcorn are development mutants, and dry matter accumulation into the endosperm is brought to a premature halt by a failure in starch synthesis.

2.1.6 Fertilizer application

Sweet corn responds well to the application of fertilizers, and ample fertilizers are usually provided to obtain maximum seed yields, especially under irrigated conditions. About three weeks after each planting, 200 kg/ha of N:P:K; 12:10:10 is applied in bands along both sides of each row, and three weeks later a side dressing of 200 kg N/ha is applied as urea (Wilson and Salinger, 1994). In Manawatu , Anon (1995) suggested that a base dressing be applied as a banded application at sowing (N:P:K = 15:15:25 kg/ha) and a side dressing be applied as a banded application

when the crop is 15-25 cm in height (250-625 kg/ha of urea). Lime may be applied as required to bring the soil pH to a level of pH 5.8 to 6.4 (Underwood, 1985).

2.1.7 Irrigation

Mackay and Eaves (1962) found that in Canada, sweetcorn was very responsive to supplementary irrigation, especially from the pollen-shedding stage to cob maturity. They also showed that removing moisture stress by increasing irrigation increased the crops response to nitrogen, phosphorus and potassium. They attributed this to the production of larger plants resulting from the irrigation. The application of irrigation at silking and later while the ears are developing is likely to be beneficial. If applied prior to silking, it may well produce large plants, but will not necessarily increase seed yield (Cordner, 1942; as cited by Salunkhe et.al.,1987). Chotena et al. (1980) subjected mid- season inbred plants of sweetcorn to moderate or high soil moisture stress at tasselling, at silking, or at 2 weeks after silking, and found that stress at 2 weeks after silking was associated with a significant reduction both in the seed yield and quality when harvested 80 days after silking, and was also associated with a significant increase in the incidence of stalk rot.

2.1.8 Pests and Diseases

Lamp (1977) stated that sweet corn is not subject to many pests and diseases. In New Zealand corn ear worm (*Heliothis zea* Boddie) is the main pest for which spraying is essential. Caterpillars hatch from eggs laid in the silks at the top of the cob. They chew progressively downwards into the cob. It is imperative to obtain a kill before the caterpillar has eaten below the cob's sheath. Spraying should begin

when the silk appears. Crops harvested earlier than mid-January may not need spraying. Corn ear worm is not usually a serious pest until well into the season, as some time is needed for populations to build up sufficiently to cause serious damage. Spraying is difficult when the crop grows higher than 40-50 cm unless specialised equipment is available. After this stage most spraying is carried out from the air at greater expense (Lamp, 1977). Cut worm (*Agrotis ipsition aneituma* (Walker)) and army caterpillar (*Mythimna separata* (Walker)) are other important pests in New Zealand; Hallmark 5 EC as an aerial application of 250 ml in 90-120 litres of water/ha can be used at the first occurrence of pest activity. Diazion 50% WP and 80% EC can also be used to control cut worm and army caterpillar. Mesurol (Mesurol contains 750 g/kg methiocarb in the form of a wettable powder) is used to dissuade birds attacking the sweet corn cobs. It is applied as a spray over the cobs twice, in early and mid April.

Sweetcorn has a few diseases (some caused by more than one pathogen) which are of economic importance. At present, northern leaf blight (*Stetosphaeria turcica*), head smut (*Sphacelotheca reiliana* (Kuehn) Clint) stalk and ear rots (*Fusarium* spp.; *Diplodia zae*) and root rot (*Fusarium* spp.; *Pythium* spp.) can be significant (Shurtleff, 1980). In general, disease can be reduced by growing resistant or tolerant cultivars, using good field husbandry and using fungicidal seed treatments.

2.1.9 Weed control

Weeds play a big part in corn and sweet corn production. It has been reported that losses in yield of corn reach up to 45% in Germany, 30% in Russia, 50% in India and 40% in Indonesia if weed are not controlled (Nieto, 1970). In New Zealand,

yield increases of 70% were reported by Patterson (1960), and Cumberland et al. (1970b) concluded that weed control not only increased the grain yield but also the number of plants surviving to harvest, and the number of cobs produced by each plant. Corn or sweet corn suffers the worst weed competition in the early stages of growth - the critical period is usually the first 30 to 40 days after emergence (Cumberland et al.,1971; Remison,1979). Broadleaf weeds usually depress maize production more than grass weeds (Rahman, 1985).

Recommendations for the control of annual grasses and some broadleaves include alachlor (which requires moisture within 10 days of application to activate it) applied at 3.36 kg in 200-400 litres of water/ha immediately after sowing. Alternatively use 2.64 kg-3.36 kg alachlor plus 1-1.75 kg atrazine/ha. The higher rate should be used on soils high in clay or organic matter. Cyanazine at 1-1.5 kg/ha may be used in place of atrazine. The addition of atrazine or cyanazine will extend the spectrum of weeds controlled. These products should not be applied after the sweet corn has emerged as injury may result (Anon, 1993).

2.1.10 Harvesting

Super sweetcorn matures at a slower rate than field corn because of its high sugar content, and ripening of super sweetcorn is closely associated with temperature. Salunkhe (1987) reported that sweet corn may be harvested by hand-picking, mechanical picking or by direct combining. In hand picking, husking pegs or hooks are generally used to remove husks from the ear, the husked ear being snapped off. The latter are either directly thrown into a wagon box in bulk or put in burlap bags attached to each picker by a belt. If the corn is to be taken directly to the seed

processing plant, it is scooped or dumped directly into a crib for curing and storage. The use of bags helps to reduce injury to the seed pericarp. In mechanical harvesting standard makes of corn-pickers are used. Snapping rolls of the machine remove ears from the plants which are then conveyed to the husking bed where most of the husks are removed by the revolving rubber rollers. The ears are then elevated into a wagon from which they are later scooped into bags and transported to the processing unit. The husking rollers of the picking machines may be removed to reduce injury to the seed of canning types of sweet corn. Ears of such cultivars are husked later by hand in one central location. Sweet corn at about 35% seed moisture content (SMC) is ideal for mechanical picking; with higher moisture there may be excessive damage from crushing and there may be too many shelling losses with lower moisture content.

2.1.11 Drying

It is necessary to reduce the seed moisture content to 15 % or lower to reduce the damage from mould and allow safe storage; some seed firms lower the moisture content to as low as 12 to 10%. Erwin and Haber (1985) stated that temperature, humidity and the rate of air flow are important factors governing the drying rate. Failure to control any one of these factors may greatly impair the germination and quality of the seed. Normal maize and sweetcorn seeds are often harvested on the ear at seed moisture as high as 49% and 55%, respectively (Herter and Burris, 1989a; Wilson and Trawatha, 1991). In sweetcorn, seeds are intolerant to high drying rates caused by high temperatures. In the field they dry very slowly (Wilson and Trawatha,1991). Even pre-conditioning at 35°C which induces tolerance (protection)

to subsequent elevated temperatures (Lindquist, 1986; Van de Venter and Lock, 1992), produced no or little increase in drying tolerance (Schleppi and Burris, 1989). Wilson and Trawatha (1991) observed that desiccation tolerance was gained very slowly in sh-2 sweetcorn and that low seed vigour resulted as a consequence of desiccation damage. They suggested that slow drying might prevent such injury. It was concluded that temperature and drying rate affected drying injury.

2.1.12 Processing

When seed is freshly harvested, it is usually unsuitable for either planting or storage. The seed may have a high moisture content and contain various contaminants such as leaves, stems, weed seeds and live and dead insects, as well as damaged and immature seeds (Salleh, 1982). The seed therefore needs to be processed before it is suitable for storage or planting. Such processing involves upgrading the quality of seed by removing foreign material and undesirable seed, improving the planting condition of the seed and applying protectants (Gregg et al., 1970; Copeland, 1976). The ultimate goal of seed processing is therefore to obtain the maximum percentage of pure crop seed with a maximum germination potential. The flow pattern of seed in a processing plant varies according to the kind of seed. Generally, however, the sequence follows the following pattern of operations (Salleh, 1982).

2.1.12.1 Drying

Pre-cleaned seeds should be dried gently, while also avoiding excessive temperature to maintain germination quality. Drying may be in single or multiple stages with or without tempering depending on the crop. After drying to a safe

moisture level, the seed is cooled and stored in bulk, preferably in ventilated bins.

During the drying process, the endosperm of super sweetcorn seed (sh-2 type) tends to dry at a different rate than the pericarp and shrinks more. Thus, the pericarp usually blisters away from the shrunken endosperm, leaving the pericarp vulnerable to mechanical damage. Also, the embryo is more exposed and more vulnerable than that of sweetcorn seed.

2.1.12.2 Cleaning

This operation is basically similar to that of precleaning but is more refined. It includes the removal of inert material, weed seeds, other crop seeds, and broken seeds that are larger or smaller than crop seed. This is generally done on an air screen cleaner.

2.1.12.3 Grading

This phase separates seeds according to physical differences. Seeds may be graded according to length, thickness, size, surface texture and shape such as flat or round seeds. All these separations can be done by screen- or disc-separation or a draper separation with velvet cloth in the case of separation according to differences in seed coat texture. This results in the retention of seed in a seed lot with similar physical characteristics.

2.1.12.4 Seed treatment

After cleaning and grading, high purity seeds can be bagged for storage or shipment. Often the seeds are treated with pesticide or fungicide chemicals just prior

to bagging to control pests and diseases. These chemical may be applied in dust or slurry form. A dye is sometimes introduced to ensure that the user will know that the seeds have been treated and are unsuitable for human consumption. In New Zealand, super sweetcorn seed is normally treated with the protectant fungicide captan (Hampton et al.,1994).

2.1.12.5 Packing

The treated seeds are weighed and packed in uniform weight bags, closed and ready for shipment or storage. The bags should be labelled to indicate the species, cultivar, grade, chemical treatment and other relevant information.

Packing the coated super sweetcorn seed and transporting it has been drastically changed from the packing and transporting of sweetcorn seed . The treated and coated seed is placed in heavy sealed plastic pouches, put into corrugated cardboard boxes, placed on pallets, and shrink-wrapped. This eliminates the mechanical damage to the coated seed that occurs when paper bags are stacked on top of one another during shipping. In paper bags, the weight of shifting seed breaks the fragile pericarp. The breakage is nearly eliminated when the coated seed is transported in boxes.

As a result, the shelling, milling,sizing, seed sorting, transporting, treating, and packaging processes have been modified to handle the elevated-sugar seed. The sheller has been modified by lowering the cylinder speed and reconstructing the cage in which the cylinder is housed to allow by-passing of the preshelled seed. The milling and sizing machinery has been modified to cope with seed half the weight and size of standard sweetcorn (Marshall, 1987).

2.2 Problems with the production of super sweetcorn (*Zea mays* L.) seed.

Shrunken (Sh-2) super sweetcorn genotypes ,have recently dominated the market because of their extra sweetness and extended post harvest grain quality. This provides longer periods for transport, process, sale and consumption of sweet corn of superior quality (Jovic et al.,1993). However, sh-2 genes are not without some drawbacks. Although they can enhance eating quality, they pose seed production problems. Achieving optimum and uniform maturing plant populations of sh-2 sweet corn is an ever challenging problem to growers and researchers, a problem which can become severe, even devastating because sh-2 seed germination is often low due to poor quality (Jovic et al.,1993). The cause of problems related to stand establishment and vigour with sh-2 genotype are numerous, and have been documented. As the seeds remain with high moisture and sugar content at harvest, delayed harvesting may occur, making the seeds liable to weathering and/or pathogen damage. If harvested at high seed moisture content, mechanical drying is necessary. This may cause mechanical and /or drying damage and seed quality reductions. Reduced starch levels in sh-2 seeds may not provide sufficient carbohydrate reserves for optimal emergence and vigorous seedling growth rates(Wann, 1980). High sugar content of seeds elevates osmotic potential, which in turn may cause membrane and pericarp damage as a result of too rapid an influx of water during imbibition (Simon, 1978). This may be associated with increased leaching of sugar such as sucrose, glucose and fructose (Caplan, 1984) from the seeds, and hence increased conductivity (Wann, 1986). Solute leakage not only reduces metabolic energy available for embryo growth during germination, but also stimulates growth of pathogenic micro-organisms which

may decrease emergence and seedling vigour significantly (eg. Styer and Cantliffe, 1984; Headrick and Pataky, 1989; Headrick et al., 1990).

2.3 Super sweetcorn and *Fusarium*

Sweet corn type of *Zea mays* are relatively more susceptible to seed rot disease because of their higher sugar content and perhaps because of a thinner seed coat than for normal maize. Lines with a relatively high fraction of lysine in the endosperm amino acids are considered to be more susceptible to the disease (Jones and Clifford, 1983). Also, the concentrated sucrose solution in the endosperm resists drying (Wilson and Trawatha, 1991) which because it is necessary to wait for seed dry down, results in a late harvest, so that seeds are subjected to weathering and/or pathogen, particularly *Fusarium*, damage.

The genus *Fusarium* is one of the most economically important genera of fungi, because it induces many pathogenic species which cause a wide range of plant diseases eg. stalk rot, cob rot, root rot of corn (Burgess et al., 1988) and some species which are highly mycotoxigenic, causing both animal and human diseases (Marasas et al., 1984; Marasas and Nelson, 1987). Neergard (1979) stated that 25% of corn production losses in the world are due to seed-borne *F. graminearum* and *Diplodia zae*, Rheeder et al., (1990) found seed -borne *F. graminearum* to have an influence on germination of sweet corn seed in the laboratory.

Fusarium spp. are well known plant pathogens, causing diseases such as cortical rots or vascular wilts, among the most important of the cosmopolitan diseases. The fungi are present in soil, air and organic material. Some species survive

well with little oxygen or water and with unusual mixtures of gases and chemicals, and flourish under extremes of sundry environmental stresses. The problem is further compounded by the fact that *Fusaria* produce mycotoxins. These are toxic secondary metabolites produced by fungi which, apart from being in some cases phytotoxic to plants and seed tissues, are detrimental to man and animals (Agarwal and Sinclair, 1987; Abbas et al., 1989).

2.3.1 Why is *Fusarium* a problem.?

Poor germination, establishment problems and below optimal and/or uneven plant populations are features of super-sweetcorn (Juvic et al., 1993) The presence of seed and soil-born pathogens, particularly *Fusarium* spp., is one of the factors that can affect the emergence and establishment performance of super sweetcorn. These losses occur as a result of post-emergence damping-off of seedling mesocotyls near ground level, and occasionally on the root systems. Species isolated from such tissue are predominantly *F.subglutinans*, *F.graminearum* and *F.poa*. The optimum temperature for growth of these pathogens is 20-25°C (Gonzales et al. 1988). Mashauri (1993) reported that super sweetcorn field emergence and emergence rates were poor, probably because of the effects of both seed-borne and soil-born *Fusarium* spp.

Corn seed left in the field after physiological maturity undergoes weathering, a process which is known to cause seed deterioration or ageing resulting in reduction in seed quality, particularly seed vigour (Harrington, 1972; Delouche, 1980; Powell, 1986; Hampton and Coolbear, 1990). Koehler (1942) found that after entering the interior of the seed, *Fusarium* spp. were found more often in the embryo than in the

endosperm. Manns and Adams (1923)(as cited by Kabeere, 1995) found that *F.moniliforme* and *F. subglutinans* grew upwards underneath the pericarp and under favourable conditions during germination, the fungi killed the embryo or attacked the seedlings, and that the roots, scutellum, and mesocotyl were the first to show the symptoms. Seeds from the tip of the ear are often rotted (Manns and Adams,1923; Sutton,1982; as cited by Kabeere, 1995) and the embryo of seeds from such ears is already destroyed (Edwards, 1936). That directly affects seed quality and particularly seed vigour.

2.3.2 What do the pathogens do.?

In maize and sweetcorn, seedling blight and root, stalk, ear, and kernel rots can occur as a result of infection with one or a complex of *Fusarium* species. The degree of damage may be negligible or devastating, depending on environmental locality and conditions, and most important, the genotype of the crop (Warren, 1978; Gulya et al., 1979). The frequently reported Fusaria (e.g. *F. moniliforme*, *F. graminearum* and *F. subglutinans*) infect maize and cause damage when the plant is under stress from biotic, climatic or edaphic causes. Styer and Cantliffe (1984) studied the infection of two endosperm mutants of sweet corn by *Fusarium moniliforme* and its effects on seedling vigour. Kernels of hybrid sweet corn plants with the recessive shrunken-2 (*sh2*) gene became heavily infected with *F. moniliforme* in the field earlier than kernels of hybrid plants with the standard sugary (*su*) gene. Mature ears of both mutants inoculated 10 days postpollination (DPP) had higher levels of rot and seed infection than those inoculated later in development. In *sh2* seeds, the pathogen appeared to enter through small cracks in the pericarp or by

appressoria. It spread throughout pocketlike areas between the pericarp and aleurone layer, and eventually moved into the endosperm and embryo. Infection increased the number of abnormal seedlings and reduced seedling growth of sh2 seeds germinated under optimal conditions. Germination of infected sh2 seeds was lower in a cold soil test and growth rates were reduced compared to those observed under optimal conditions. Poor seed and seedling vigour of sh2 was due, in part, to infection with *F. moniliforme* but this did not appear to be the primary factor involved in the loss of vigour. Under stress conditions, uninfected sh2 seeds had less germination and vigour than uninfected su seeds.

In the field, persistent rainfall in corn favours epidemic disease development caused by *F. graminearum*, and indirectly increases ear rot and accumulation of the mycotoxin Zearalenone (Sutton et al., 1980a). Rainfall and warm temperatures during the period of greatest host receptivity are critical for infection and development of ear rot and Zearalenone accumulation (Koehler, 1959; Tuite et al., 1974; Caldwell et al., 1974). Hampton, et al., (1994) found that seed-borne *F. subglutinans*, and *F. graminearum* were likely to be the major causes of poor field performance of super sweetcorn in the Manawatu. Corn cob rot disease is a world wide problem (Marasas et al., 1979; Cook, 1981). The New Zealand climate has been described by Lauren et al., (1991) as being generally favourable for the growth of *Fusarium* spp. including *F. graminearum*, and the production of mycotoxins (Hussein et al., 1989; Lauren et al., 1991). *Fusarium* infected maize grain usually contain mycotoxins, such as Zearalenone and trichothecenes (Sutton et al., 1980b; Sutton, 1982). Delayed harvest increases seed invasion and the intensity of cob rot due to *Fusarium* spp. (Koehler, 1942; Hesseltine and Bothast, 1977; Sutton, 1982) which also increases

mycotoxin levels (Sutton, 1982; Neish, et al., 1983). Infection of maize and corn cobs (Koehler, 1942, 1959; Sutton, 1982) continues during seed development, and under favourable conditions of seed moisture content and temperature (Sutton and Baliko, 1981; Sutton, 1982).

2.3.3 What makes *Fusarium* more of a problem in super sweetcorn than other sweetcorn.?

Seed produced in the field may be contaminated with *Fusarium* spp. *Fusarium* spp. are more of a problem in super sweetcorn than other sweetcorn, because of higher sugar content which acts as a more favourable substrate for *Fusarium* growth and development. Under the correct conditions of temperature, water availability, pH and nutrient supply, *Fusarium* in infected seeds together with *Fusarium* fungal structures associated with the surface of the seeds, will germinate and any seed in proximity could become infected (Agarwal and Sinclair, 1987). Physically and mechanically damaged seeds are thus more prone to soil-borne or seed-borne *Fusarium* infection (Neergaard, 1977). During seed germination there is leakage of carbohydrates and amino acids from the seed and these can stimulate spore germination in the soil or on the seed surface, and thus aid the infection process (Short and Lacy,; Agarwal and Sinclair, 1987). Low vigour seeds which leach more electrolyte than high vigour seeds are thus more susceptible to fungal attack (Harman, 1983). Agarwal and Sinclair (1987) stated that moisture levels and atmospheric temperature are important factors in controlling spore germination in the soil, the infection process and the subsequent disease development. Shurtleff (1980) showed that pre- and post emergence diseases of maize caused by soil-borne or seed-

borne *Fusarium* fungi are prevalent in poorly drained, excessively compacted or in cold (less than 10-13°C) and wet soil. The degree of damage may be negligible or devastating, depending on environmental locality and conditions, and most important, the genotype of the crop (Warren,1978; Gulya et al.1979). Hampton et al., (1994) found that seed-borne *F. subglutinans* and soil-borne *F. graminearum* were likely to be the major causes of poor field performance of super sweetcorn cv. Illini Gold.

2.4 Other seed quality aspects of super sweetcorn

2.4.1 Germination

Germination is defined as the emergence and development from the seed embryo of those essential structures which indicate its ability to develop into a normal plant under favourable condition in soil (ISTA, 1993). Germination testing is designed to provide information about the planting value of a seed lot, and remains the principle and internationally accepted criterion for seed viability. A germination test result less than an accepted standard indicates that the quality of the seed lot is suspect, and that there may be future problems with field emergence or ability to be stored (Hampton and Coolbear, 1990). Therefore the germination test seems adequate to indicate quality attributes of the seed except at high germination values (Roberts, 1984) when, because of the nature of the normal distribution on which the seed survival curve is based, a small difference in percentage germination represents a large difference in the progress of seed deterioration (Ellis and Roberts, 1980). The reason for performance differences between high quality seed lots is ascribed to seed vigour, a further component of seed quality, and in these circumstances, vigour

becomes important and vigour testing necessary (Hampton and Coolbear, 1990).

In laboratory tests, germination of super sweetcorn is better in sand than between paper. By growing in sand the root system is also clearer to evaluate. Super sweetcorn does not do well under stressful conditions i.e. vigour testing under low temperature condition leads to poorer germination than sweetcorn and maize, possibly because the endosperm is very small and can not take excess stress (R.Morrison,Seed Tech.Services, Massey University;pers.comm.). Mashauri (1993) stated that super sweetcorn field emergence and emergence rates were poor, but probably because the effect of both seed-borne and soil-borne *Fusarium* spp. on chemically untreated seeds masked any other seed quality difference.

2.4.2 Thousand seed weight

Seed size is usually expressed as the weight of a thousand seeds (Thomson, 1979). The thousand seed weight depends on variety and on the conditions prevailing during the entire growing season of a seed crop. When the seed is used for sowing purposes, thousand seed weight has a greater effect on the sowing rate. Heydecker (1972) observed that the heaviest seeds often have the highest percentage germination, but not necessary the best field performance (Hampton and TeKrony, 1995).

Increasing thousand seed weight means increased food reserve into the seed which might supply nutrition to the initial development stage of the sweetcorn seedling. In sweetcorn, increases in seed protein resulting from supplemental nitrogen application can result in improved seedling performance (Schweizer and Ries, 1969).

2.4.3 Vigour

Seed vigour has been defined as those properties of a seed lot which determine its potential to rapidly produce a uniform and healthy plant stand under a wide range of field conditions (AOSA,1983). Seed vigour may be viewed as the potential of a seed lot to germinate, emerge rapidly or store well under less than optimal environmental conditions (Hampton and Coolbear, 1990). Maximum seed quality occurs at mass maturity, when maximum seed dry weight is attained, after which vigour and viability can deteriorate both pre-and post- harvest. Loss of vigour may result from a matrix of inter-related deteriorative processes involved with seed ageing, which may be viewed as an inevitable consequence of initial membrane deterioration. As deterioration increases, both field emergence and storability decrease (Delouche and Baskin,1973), and the seed lot will exhibit ageing symptoms including a slow rate of germination and emergence, poor seedling growth, decreased tolerance to sub-optimal conditions, low oxygen uptake during the early stage of germination and enhanced solute leakage. However, there are distinct, though interacting, factors such as genetic constitution, environmental conditions during seed development, tolerance/susceptibility to mechanical or heat damage during harvesting, drying and cleaning, storage conditions and pathogens which are fundamental factors considered to influence vigour potential through their effects on membrane integrity. Seed vigour is further discussed in the following section of this review.

2.5 Seed Vigour

Seed vigour is not a single measurable property, like germination, but a

concept describing several characteristics associated with various areas of performance of the seed, both in the field and in storage. Seed vigour is therefore defined by ISTA (1993) as "the sum total of those properties of the seed which determine the level of activity and performance of the seed or seed lot during germination and seedling emergence. Seeds which perform well are termed 'high vigour' seeds". Particular 'aspects of performance with seed vigour include:

- (i) rate and uniformity of seed germination and seedling growth.
- (ii) field performance, including extent, rate and uniformity of seedling emergence, the effects of which may persist to affect mature plant growth, crop uniformity and yield.
- (iii) performance after storage and transport, particularly the retention of germination capacity.

Abdul-Baki (1980) stated that in general, vigour on the level of an individual seed means one seed producing one normal seedling which will produce a plant of marketable product. In that respect, vigour is a function of the rate of seedling emergence, of plant growth and of development in relation to the maximal rate for that variety. Vigour on the level of a population of seeds, may be expressed as rapid, uniform, and high germination or field emergence. And also vigour is a measurable physiological attribute of seed that is expressed as rapid, uniform and high germination or emergence even under unfavourable conditions.

Seed vigour is a very important character in super sweetcorn and must be high during planting so that the seed can resist the many environmental factors

affecting germination and field establishment. Planting low vigour seeds can result in economic loss, resulting from emergence failure necessitating resowing, and often causing a delay in harvest. This can lead to a fall in market prices, and lower profits from the harvest (Matthews and Powell, 1986).

Maximum seed quality occurs at physiology maturity, the point when maximum dry seed weight is attained, after which vigour and viability decline during ageing on the plant (Delouche, 1980), during harvesting, during processing and during storage (Powell et al., 1984). Seed ageing has come to be recognized as the major cause of reduced seed vigour and viability, and involves the deterioration process, i.e. the accumulation of irreversible degenerative changes until eventually the ability to germination is lost (Powell, 1988). While physiological and physical damage to cell membranes is likely to be the fundamental cause of seed deterioration, enzyme, respiration and hormonal changes, impaired protein and RNA synthesis, genetic change, and accumulation of toxic metabolites are also involved (Hampton, 1994).

It is possible that many or all of these forms of degradation can occur to some extent within a single seed, but no doubt certain deterioration processes will be more important than others, depending on species and ageing environment (Priestley, 1986). Powell (1988) reviewed of the physiological and biochemical changes which occur during seed ageing, and presented evidence strongly supporting the hypothesis that the deteriorative metabolic changes observed in aged seeds are the inevitable consequence of initial cell membrane deterioration. Similarly the physical disruption of the membranes, i.e. rapid uptake of water during imbibition (Powell et al., 1984), prevents normal cell organisation and hence leads to impaired performance. It seems

increasingly likely that cell membrane integrity, determined by deteriorative biochemical changes, and/or physical disruption, can therefore be considered to be a fundamental cause of differences in seed vigour (Powell, 1986; Matthews and Powell, 1986; Powell, 1988). However, there are distinct, though interacting, factors such as environment and nutrition of the mother plant, stage of maturity at harvest, mechanical integrity and pathogens which are fundamental factors considered to influence vigour potential through their effects on membrane integrity.

2.5.1 Production factors affecting seed vigour.

2.5.1.1 Environmental conditions during seed development and nutrition of the mother plant.

The environment plays a vital role in the development of the seed from the flower to seed maturity (Delouche, 1980). Low humidity, minimal rainfall, and favourable temperatures reduce the spread of seed borne diseases as well as the risk associated with inclement weather during the later maturation and harvest periods. Maturing seed can be damaged on the mother plant by insects, birds, rodents and rabbits. These can affect the subsequent performance of the seed. Additionally, pathogens may invade the seeds through the damaged areas, or can be internally transported to the seed tissue as a result of systemic infection (Neergaard, 1977). Once infection has occurred, be it from internal or external sources, the pathogen can cause diseases e.g. *Fusarium* spp. may cause a severe ear and/or kernel rot, (Shurteff, 1980).

Temperature during seed development and maturation may affect the potential

performance of the seeds. In maize, increased temperature reduced the duration of the linear phase of kernel growth (Badu-Apraku et al.,1983). Thermal effects may impair the endosperm cell division process, causing a severe reduction in number and/or size of endosperm cells or starch granule formation (Radley, 1978; Jones et al.,1985) that may subsequently reduce seed weight and hence vigour level.

Climatic conditions during the post-maturation and pre-harvest period also have a great influence on the quality of seed harvested (Delouche, 1980). Maximum seed quality occurs at physiological maturity after which vigour and viability decline because of the ageing process of the seed (Delouche,1980; Powell,1988). Seed moisture content and temperature are considered as major factors influencing the extent of seed ageing: an increase in either or both accelerates ageing. Seed ageing on the plant is frequently referred to as " weathering", reflecting the influence of these factors (Matthews and Powell,1986). Weathering is a major problem in seed production. The severity of weathering and the limitation imposed on seed quality by weathering generally increases from cool to warm areas. The worst situation is in the humid subtropics and tropics, where the quality of seed produced is generally low and deterioration continues at a rapid rate during storage because of high temperatures and humidities (Delouche,1980).

In term of plant nutrition, crop fertilizer requirements have tended to be managed for optimising seed yield rather than seed quality. However, in order to obtain satisfactory yield and quality levels, there is need to consider also the nutrient requirements for seed quality rather than just for quantity (Delouche, 1980: Hampton, 1990). Nitrogen, phosphorus and potassium have been the main nutrients examined. Hadavizadeh and George (1989) showed that the interaction of high nitrogen

(i.e.1000 mg/plant) with medium phosphorus supply (i.e.250 mg and 500 mg/plant) produced an increase in seed vigour in garden pea. However, potassium nutrition was found to have very little effect on yield and vigour of pea seed.

2.5.1.2 The important of seed intactness (Mechanical Damage).

Mechanical damage incurred during seed processing is obviously influenced by seed moisture content and the severity of machinery use (Moore, 1972; Justice and Bass, 1978). One of the most important causes of low vigour is seed coat damage or cracking by machine incurred during harvesting very dry seed (Gane et al.,1984). Mechanical damage, quite apart from curtailing the food supply available during germination and the early stages of growth, or even injuring the embryonic organs, provides a focus for colonisation by saprophytes (Heydecker, 1972)

There is plenty of evidence which shows that however good the initial quality of seeds, they deteriorate more rapidly if they have been mechanically injured in some way (Roos, 1980). Sources of mechanical damage are the operation of 1) harvesting 2) threshing 3) processing, cleaning and transportation within the warehouse and 4) handing during planting(drilling). Three levels of mechanical damage are recognised (Pollock and Roos, 1972):

1) slight injuries in the form of microscopic breaks, particularly in the seed coat, which make the seed susceptible to attack by microorganisms

2) gross damage to seed and seed coat, easily visible;

3) internal damage, often injury to the embryo, being visible usually only after the seed has germinated.

These cause

- 1) loss or damage of tissue and hence of viability
- 2) loss of capacity in regulating the water content of the seed
- 3) increased susceptibility to invasion by microorganisms
- 4) increased susceptibility to phytotoxic effects

The nature of mechanical damage varies widely. The most intensive injuries reduce viability immediately, whereas small injuries often do not cause an immediate loss in viability, but become increasingly apparent as ageing occurs. In seeds that are extremely dry and brittle, fracturing is the predominant type of injury, while bruising tend to be prevalent in moist seeds (Moore, 1972).

Damage may be caused during maturation even without any interference by man (Delouche, 1980; Perry, 1980; Matthews and Powell, 1988). More frequently it is, however, due to faulty threshing or processing methods (Gane et al.,1984) or careless handling of sacks of seeds in transit (Gleeson, 1987). The degree of damage depends on the interaction of several effects such as seed moisture content, drum speed of the threshing machine and seed varieties.

Drum speed of the threshing machine is also closely associated with mechanical damage. Saini et al.,(1982) examined the effect of drum speed on soybean, and found that high drum speeds gave relatively lower quality results and proportionally lower quality after storage than lower drum speeds. The kind of seed is another of the significant factors influencing mechanical damage in seeds. The weight and size of the large-seeded Gramineae, in particular, tend to make them especially susceptible to injuries that reduce viability.

2.5.1.3 The effect of nitrogen on seed quality and particularly seed vigour.

The effects of nitrogen on seed production can be divided into two broad areas of concern : (1) seed yields and (2) seed quality particularly seed vigour. Levels of soil fertility and moisture supply influences sink size and weight, and there is evidence that seed weight is associated with germination and vigour (Heydecker, 1972; Austin, 1972; Ueyama, 1975; Odiemah, 1985), but there is also evidence suggesting the opposite (e.g. Smith and Camper, 1975). Underwood (1985) reported that a large proportion of the nitrogen and phosphorus taken up by the plant is removed in the seed, but most of the potassium remains in the leaves and stalks (Larson and Hanway, 1977). In a field trial in 1987 on a Honeoye fine sandy loam, sweetcorn cv. Jubilee seedlings were given 0-20 kg N/m of row as urea, ammonium nitrate, ammonium sulphate or calcium nitrate at sowing (on 27 May or 22 June) placed in a band (together with 5 g P and 5 g K) at 5 cm below the seed depth and to one side of seeds. Seedlings given ammonium sulphate or ammonium nitrate grew more rapidly than those given urea, especially at the higher N rates, and much more rapidly than those given calcium nitrate at all N rates and for both sowing dates. Seedling fresh weight and dry weight was greatest in plants given approx 0.3 g N/m of row. Seedling P concentration was higher when N was supplied as ammonium sulphate or ammonium nitrate than as urea or calcium nitrate. Seedlings given ammonium sulphate had lower nitrate-N and Ca concentration than those given the other N sources. Seedling Ca and Mg concentration were higher and Zn and Mn concentration lower when N was supplied as calcium nitrate when compared with other N sources (Peck et al., 1989).

The effects of nitrogen have been reviewed by Gray and Thomas (1982). Nitrogen fertilization can have adverse effects on both seed weight and total seed yield per plant by delaying crop ripening. As a result,more immature seeds are produced with less vigour and lower germination potential. Taber and Cox (1975) investigated the effects of nitrogen on yield and seed protein content of sweet corn grown on sandy soils. They found that increasing the N rate from 56 to 224 kg/ha increased the yield, ear leaf N concentration, and seed protein content of sweet corn (cv. Midway).

Increasing nitrogen decreases oil content while it concurrently increases protein content of the grain. Langer (1966) suggested that increases in seed protein resulting from supplemental nitrogen applications or chemical treatment can result in increased seed vigour. Schweizer and Ries (1969) reported that increasing the nitrogen supply to wheat plant not only increased the protein content of their grain but also significantly increased the yield of the progeny produced from the enriched-protein grain.

Nitrogen supply apparently affects the synthesis of certain endogenous proteins or proteinaceous moisture in grain which can increase seedling growth rates and ,therefore, seedling vigour. Gray and Thomas (1982) suggested that mineral nutrients,such as nitrogen, can change the concentration of phytohormones (e.g. cytokinin) in seed and via this means influence the accumulation of protein and carbohydrates in seeds. Possibly,the effects of nitrogen on seed vigour are the result of changes in levels of certain phytohormones in the parent or seed during seed development.

Ross (1985) reported that the form of nitrogen supplied (e.g. nitrate, ammonia,

or urea) can also affect protein accumulation in grains. Also, denitrification rates and availability of nitrogen source are important factors. The time of nitrogen application can also affect the response of protein in cereal grains, with maximum protein content being obtained when nitrogen supply is continuous and at adequate levels during the grain-filling period. High positive correlations have been reported between high protein content and seedling vigour, and interactions of nitrogen and phosphorus nutrition supplies to the mother plant have been reported to increase vigour in peas (Hadazavideh and George, 1988). Nitrogen and phosphorus are major constituents of proteins and phospholipids, which are the building blocks of cell membranes. The stability of membrane structure depends largely on the solubility properties of these molecules. Because of this the interaction effect of nitrogen and phosphorus nutrition on seed vigour can be revealed as electroconductivity values during seed imbibition (Hadazavideh and George, 1989; Coolbear, 1995). Deficiencies in these elements may thus affect membrane permeability through effects on the protein and phospholipid components of membranes.

2.5.1.4 Genotype

Genotype can have a significant effect on seed quality, and there is considerable evidence of genotype differences in seed quality characteristics which indirectly influence seed quality. There are many reports of genotype differences in seed quality characteristics responsible for successful and rapid establishment in maize crops. For example, Burriss (1977) showed that some inbred lines had a highly significantly greater germination, shoot and root dry weights compared with other inbred lines, and Barla-Szabo et al. (1990) demonstrated that shoots of some inbred

lines were significantly longer than others. Many workers (eg. Eagles and Hardacre, 1979; Eagles and Brooking, 1981) have demonstrated genotype differences in germination, germination rate and seedling vigour at low temperature in maize. The genetic control of this low temperature stress characteristic has been investigated. The work of Eagles and Hardacre (1979) indicated that maternal effects appeared to be of considerable importance for germination percentage at low temperature in maize, while the results of Eagles (1982) suggested that genotype of the embryo and endosperm was of much greater importance than the genotype of the maternal parent in determining differences in time to emergence and seedling growth at low temperatures.

2.5.1.5 Time and method of harvest

Harvest timing is one of the most important factors affecting the maximum seed potential performance in sweetcorn, because harvesting too early, too late, too dry or too wet may be detrimental to the seeds. Harvesting too early may terminate in small, immature and shrivelled seeds of poor quality due to inadequate food reserves, while harvesting too late may cause losses of seed quality due to sprouting, weathering damage, insects, birds and mould attack. While harvesting too dry makes the seeds liable to cracking damage or breakage, harvesting too wet and with improper harvesting techniques may result in bruising damage associated with internal disruption, all of which result in seed of doubtful field planting value. In addition to this, seeds with high moisture content are more susceptible to drying damage. Harvesting at the right stage and with the properly adjusted equipment or drying with accurate methods and properly adjusted temperatures is essential for minimising mechanical injury, drying damage, field deterioration, damage by birds,

rodents or moulds. Monitoring changes taking place during seed development is thus of particular importance, as they can be used to assess seed maturity and indicate the correct time for harvesting. Furthermore, seed development knowledge is very useful during the subsequent seed drying after harvest, as the seed moisture content determines the subsequent method of drying, type of dryer, and setting or adjustment of safe air flow rate and temperature.

Mechanical damage is one of the main factors responsible for decreased seed quality (Chazov,1967; Stron,1972). Mechanisation of harvest and post-harvest procedures for grain crops increases the incidence of mechanical damage to seed. Assessment of the germination of wheat and barley has shown that germination after whole-crop harvesting may be reduced by up to 20% compared with hand harvesting (Anon,1979). For maize, mechanical damage has been reported to be as high as 90-95% (Stron,1980; Kaliuzhnyi and Litvinenko,1985). During processing, the seed can be exposed to damage during, cleaning,sizing,storage and transport, which can decrease seed vigour.

Seeds with damaged embryos either give rise to weak seedlings or fail to germinate (Chazov,1967).Damage to maize seeds exposes them to infections by different types of fungal pathogens (Koehler,1957; Tatum and Zuber,1943). In fact, the influence of seed coat damage on disease susceptibility from *Pythium* spp.,*Penicillium* spp. *Aspergillus* spp.,and other fungi has been proposed as the primary factor for reduced germination and yield of damaged maize. The embryo, specifically the central part of the embryo, was found to be most sensitive to mechanical damage. Such damage results in injuring the delicate structures that

constitute the future plant and disrupts normal physiological activities of the seed (Kizilov,1960; Ovcharov,1969; Suhorukov,1971).

Funk,et al.,(1962) recorded significant differences in field performance and seed yield of field corn obtained from plants grown from different seed lots of the same hybrid. Plants grown from poor quality seed had slower emergence, had less seedling vigour and reduced competitive ability and were lower yielding in comparison with plants grown from high quality seed.

Jahufer,et al.,(1992) recommended that the method to control mechanical seed damage and reduce the deleterious effects of seed injury should be integrated into harvesting and post harvest activities. This will enhance production of high quality seed, and result in increasing field germination, decreasing seedling abnormalities, increased plant survival, better plant development,and increased grain yield.

The safe moisture content for shelling maize according to Hall and Johnson (1970) is in the range of 17-24% SMC. Jindal et al.(1979) observed the lowest damage at about 25% SMC while Waelti and Buchele (1969) and Pierce and Hanna (1985) found a rapid increase in seed damage as seed moisture content rose above 20%. However, Mashauri (1992) reported that the seed moisture content just below 25% seemed most appropriate for mechanical shelling of seed and that the speed of the cylinder should be as low as possible. However, threshing speeds and moisture content threshing for maize are also depended on genotype (Mashauri, et al., 1993). Nascimento et al. (1994) reported that sweetcorn cv. Doce-Cristal seeds harvested manually and threshed manually or mechanically, as well as harvested and threshed mechanically were evaluated for percentage of damage and its effects on the physiological quality of the seeds. Seed damage increased with increasing

mechanization, and mechanical damage significantly decreased seed vigour.

The ability to germinate and subsequent seedling vigour are both related to seed weight and to the amount of food reserves contained in the seed. Seeds should therefore not be harvested until they reach maximum viability (Hyde et al. 1959; Griffiths et al. 1967). If seeds are harvested too early, most will still be immature and lose viability rapidly (Hyde 1950; Hyde et al. 1959). If seeds are harvested before physiological maturity, they are generally undersized and become shrivelled on drying. They are also difficult to recover during threshing, are susceptible to threshing damage and are difficult to dry. In addition they do not store well and have low germination capacity and vigour (Hyde et al. 1959).

At physiological maturity the vascular system connecting the plant and seed is broken by an abscission layer. In maize the appearance of a black layer near the tip of the kernel signals that the transport of photosynthates into the seeds has stopped. When this occurs, the seed has reached maximum dry weight (Aldrich et al., 1975). Daynard (1972) and Daynard and Duncan (1969) have stated that in maize the black layer formation serves as a reliable and easily determined indicator of maturity. However more recently, Pieta-Filho (1992) has found that in wheat and barley maximum seed quality generally occurred between 10 and 20 day after physiological maturity.

Physiological maturity occurs when the seed moisture content is still high so that seeds need to dry-down before threshing. Shaw and Loomis (1950) distinguished between physiological maturity of maize seed at 30-40% seed moisture content, when dry matter accumulation is complete, and harvest maturity at about 20% seed moisture content. Harvesting of a seed crop as soon as it is matured reduces the risk

of freezing injury, reduces the risk of delays due to adverse weather conditions, avoids excessive field losses from mechanical pickers, reduces losses from insect damage and reduce losses from ear and stalk rot and other diseases (Williams, 1977) which result in low seed quality and particularly seed vigour.

Seed moisture content is one of the most important factors affecting loss of seed quality. The amount of water present in seed has a major effect on seed quality, particularly in relation to the amount of damage to seed which occurs during threshing, drying, cleaning and storage. The seed moisture content is important because seeds are living material and therefore respire, and respiration produces both heat and water as a by-product. If the amount of heat or water present is too high the seed will be susceptible to shelling damage, insect attack, mould growth and seed death. Pradhan (1981) who sampled cobs of sweet corn (*Zea mays L.*) cv. Golden Bantam, every 17 days after peak flowering (DAPF.) until 106 DAPE, found that as harvest was delayed beyond physiological maturity there was increasing infection by field fungi.

Menezes et al. (1992) recommended that for sweetcorn seed, manual harvesting should be carried out at physiological maturity, when moisture content is between 32.5 and 38.4%, followed by immediate drying of the seeds in the cobs.

Wilson and Trawatha (1991) reported that crops of sweetcorn cv. Florida Staysweet seed were produced in Parma in 1987-88 from sowing dates in April, May and June in each year and harvested 42-90 day after silking (DAS). It was concluded that early harvest (45 to 60 DAS.) resulted in seed with high germination but low vigour. Leaving the crop in the field for as long as 80 to 90 day after silking resulted in the consistent production of relatively high vigour seed.

CHAPTER 3 MATERIALS AND METHODS

Materials and Methods

3.1 Field trial

The trial site was located on the Massey University Campus Plots (adjacent to the Southern Access Road). The soil was classified as an Ohakea silt loam and a soil test revealed a , pH 6.2, low P (Olsen P=13), low K (Exch K=0.52), medium Ca (Exch. Ca=9.0).The soil test was conducted by the Fertilizer and Lime Research Centre, Massey University. In the previous season (1993-1994) the area was planted in various experimental annual crops including barley, pea, wheat,viola and lupin, but had been follow for the previous six months. On 10 November 1994, the site was disced, then power-harrowed to prepare the seedbed. Super sweetcorn (*Zea mays* L.) cv "Illini Gold" was used in this study. Seed was purchased from Watkin Seeds Ltd, New Plymouth. Seeds were sown by hand on 25 November 1994.

The experiment was a randomised, split-split plot design with 4 replicates (Figure 1). The main treatments, three nitrogen levels (0,100 and 200 kg N/ha) and two fungicide levels (spray, no spray) and each main treatment split into six sub-plots for three harvest times and two harvest methods. The plot size was 8.5 m x 12.0 m, rows were 75 cm apart and seeds were sown 25 cm apart within the rows at a depth of 2-3 cm. The total number of plots was 144. Two seeds were planted per hole and seedlings were reduced to one per position , 7 days after emergence. In positions where no seedlings emerged the gaps were filled by resowing. The field was sprayed with alachlor (Alachlor 480 EC) rate 7 l/ha and atrazine (Gesaprim 500 FW) rate 3

l/ha herbicide 10 days after sowing for control of annual and perennial grass and broad leaf weeds (Anon,1990 ;Anon,1993).

As little rain fall during late November (Appendix 1), plots weres irrigated for approximately 2 weeks to ensure adequate seedling emergence and plant establishment. The field plots were irrigated using an aluminium pipe (internal pipe diameter was 43 mm) which ran the length of the trial and required shifting four times to cover all of the plants. The system was capable of delivering approximately 28 l/m²/h of watering. Timing of irrigation was at infrequent intervals depending on rainfall.

Phosphorus was applied at 25 kg P₂O₅ /ha as a basal dressing to the trial site by broadcasting before planting. Nitrogen applications (urea, 46%N) were made according to treatments at three times. The first application at a rate of 0,50 and 100 kg N/ha(i.e half the total) was made 15 days after planting as a side dressing .The second application at a rate of 0,25 and 50 kg N/ha(a further 25%) was made 50 days after emergence, and the third application at a rate 0,25 and 50 kg N/ha(the last 25%) was made 30 days after silking. The nitrogen application was split because nitrogen can easily be lost by volatilizing into the air and into the soil before it can be absorbed by the super sweetcorn. Super sweetcorn needs nitrogen at all it's different growth stages and therefore the split applications were at significant growth stages of the plant i.e. after emergence, at silking and during seed development (Finck, 1982).

The fungicide Sportak 45EC 55 ml/15 l water was used in this study because it is a broad spectrum fungicide which is recommended against *Fusarium* spp. for monocotyledonous crops (Anon, 1993). It was mixed with Landmark spray marker

dye (rate 5 ml/15 l water) to indicate where fungicide had been sprayed, and Raingard (rate 3 ml/15 l water) to prevent the fungicide from washing off the leaves when it rained. The fungicide was sprayed by knapsack sprayer at 50 days (silking stage), 70 days (blister stage, see Plate 1) and 95 days after emergence (dent stage-physiology maturity). These stages (Ritchie and Hanway, 1982), during seed development (i.e. peak silking stage to physiology maturity) were recorded by observation (Kabeere, 1995).

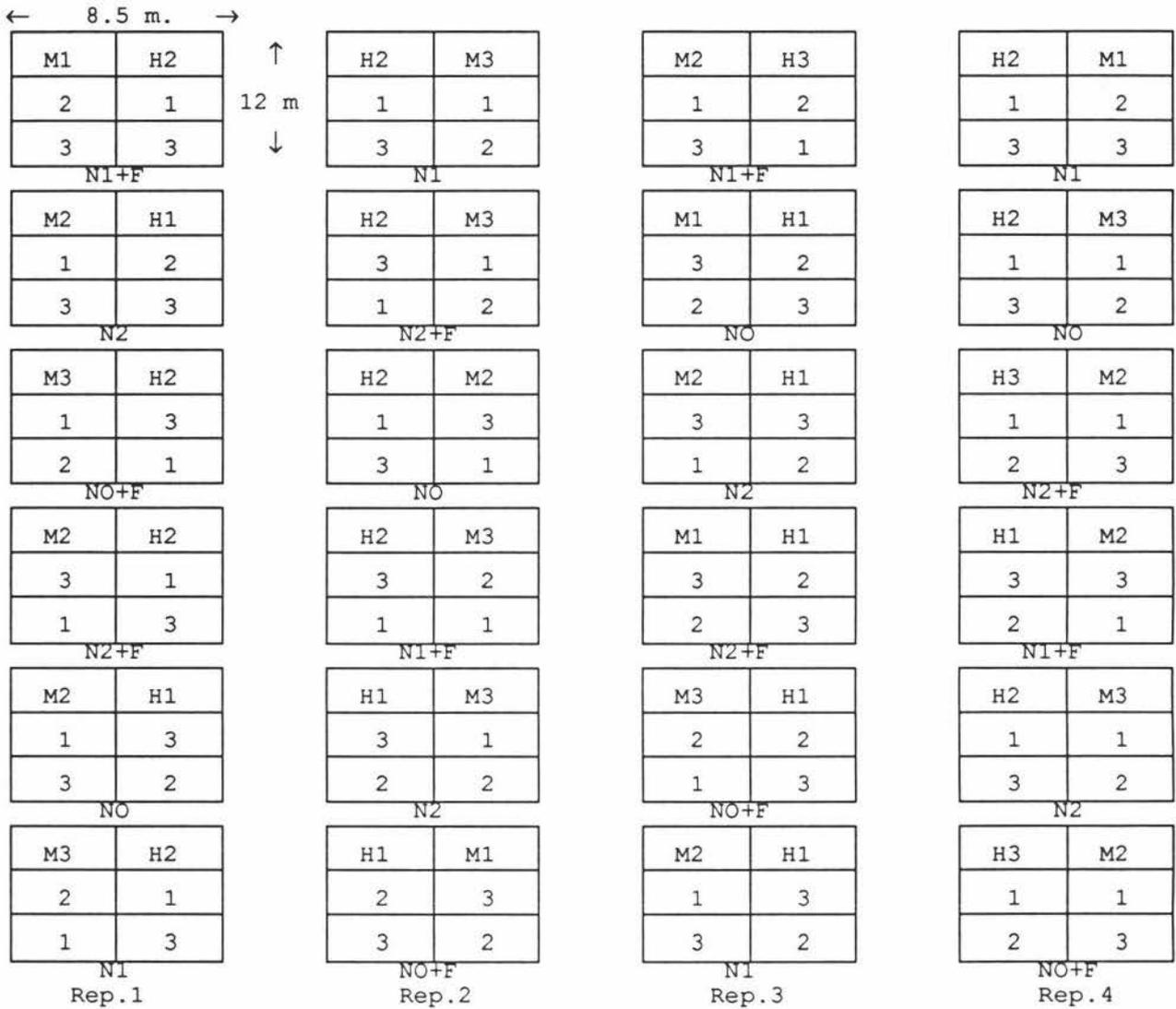
Hallmark 5EC (rate 3 ml/l of water) was sprayed by knapsack sprayer to prevent cutworm, corn earworm and army caterpillar attack. These applications were made after emergence and silking (Watson and Hill, 1985).

Mesurool (750 g/kg methiocarb) was sprayed at a rate of 3.3 g/l of water, by knapsack sprayer to prevent bird damage (Plate 2). Applications were made every 15 days from the dent stage until seed maturity.

Three cobs from each treatment were randomly sampled at approximately 3 day intervals (physiology maturity approximately 50-60 days after silking) for seed moisture determination from border row to determine when seed moisture content (SMC) had reached the required harvest levels of 35%, 25% and 15% SMC respectively. Seed moisture was determined by internationally agreed methodology (ISTA, 1993 see 2.1.1). Harvest timing at 35%, 25% and 15% SMC was used to investigate the influence of harvest timing on seed vigour. The first harvest (35% SMC) began on May 6, 1995 (56 days after silking), the second harvest (25% SMC) was taken on May 16, 1995 (66 days after silking) and the final harvest (15% SMC) was made on 23 May 1995 (73 days after silking).

At each harvest time, 30 cobs from each sub-plot were hand picked. For hand

The Field Lay-out



NO = 0 kg. N/ha
 N1 = 100 kg. N/ha
 N2 = 200 kg. N/ha
 F = Fungicide sprayed
 H = Hand-shelling
 M = Threshing machine
 1 = 35 % SMC
 2 = 25 % SMC
 3 = 15 % SMC

Figure 1 The field layout for experiments.

Split split plot Design



Plate 1. Field trial Super-sweetcorn cv. Illini Gold



Plate 2. Bird damage to mature cobs



Plate 3. The Almaco STB sheller machine

shelling, 15 cobs were hand shelled and all seed bulked together. For machine-threshing, the other 15 hand-harvested cobs were threshed by a stationary thresher (The Almaco STB sheller machine, see Plate 3) at a drum speed of 396 rpm. Mashauri et.al.(1992) had compared shelling with this machine at 570 and 954 rpm. and found a significant level of damage to pure seed threshed even at the slowest speed. Therefore a lower speed (300 rpm.) was initially used, but this often caused the cobs to "jam", so the speed was increased to 396 rpm. to decrease jamming but at the same time keep damage to a minimum.

After threshing, seed was immediately ambient air dried down to a moisture content below 12% by laying the seeds on plastic trays in a glasshouse at the Seed Technology Centre, and turning the seeds regularly. After drying, all seeds from each treatment were put in plastic bags and placed in plastic buckets with lids in a 5^oC room until the evaluation of seed quality.

3.2 Seed quality determination

3.2.1 Standard Tests

3.2.1.1 Seed Moisture Content Determination

Seeds were randomly drawn by hand approximately 10 g. were ground, placed in duplicate aluminium containers, covered and weighed, and then the covers removed and dried using the high constant temperature oven method of 130^oc for four hours (ISTA,1993). The containers were then covered and placed in a desiccator to cool for 30 minutes before reweighing . Moisture content was calculated and expressed as a percentage on a fresh weight basis using the following formula

$$\%SMC = \frac{M_2 - M_3}{M_2 - M_1} \times 100$$

where M_1 = the weight in grams of the container and cover

M_2 = the weight in grams of the container, cover and contents before drying

M_3 = the weight in grams of the container, cover and contents after drying

3.2.1.2 Standard Germination test

The between paper (BP) method (ISTA,1993) was used. Four replicates of fifty seeds from each treatment were germinated at 25°C for 7 days. Normal seedlings, abnormal seedlings and dead seeds were counted and the results expressed as a percentage (ISTA, 1993). Normal seedlings in this study are seedlings which show the potential for continued development into satisfactory plants when grown under favourable condition (ISTA,1993). Seedlings with the following defects were classified as abnormal:

a) Damaged seedlings (ISTA, 1993)

Seedlings with any missing or badly damaged essential structures. Damage can be a result of external factors such as mechanical handling. Typical abnormal seedlings are those with cracked or split coleoptiles; cracked mesocotyls; no cotyledons; split, stunted or missing primary roots with insufficient secondary root or no root (Plate 8).

b) Deformed or unbalanced seedlings (ISTA, 1993)

These are seedlings with weak or unbalanced development of the essential

structures. They may be caused by earlier external influences such as unfavourable growing conditions of the parent plant; poor ripening conditions for the seed; premature harvesting effects of pesticides; poor cleaning procedures or inappropriate storage conditions or as a result of genetic factors or natural ageing of the seeds. Abnormalities included in this group are seedlings with retarded or spindly primary roots; stunted roots; short and thick, looping or twisted mesocotyl or coleoptile or leaves which are shattered or split longitudinally.

c) Decayed seedlings (ISTA, 1993)

These include seedlings with any of the essential structures so badly decayed, due to primary fungal infection, that normal develop is prevented. It also includes dead seeds found to be mouldy.

3.2.1.3 Thousand seed weight

The thousand seed weight (TSW) was determined for all treatments. TSW for each treatment was determined by counting eight replicates of 100 seeds, and the mean TSW calculated from the average weight of 100 seeds multiplied by ten. (ISTA, 1993).

3.2.1.4 Seed health testing

Samples from all treatments were tested for fungal infection using potato dextrose agar (PDA). Preparation of PDA was done by mixing 39 g. of dehydrated PDA with 0.05 gm of chloramphenicol and dissolving in 1 litre of tap water. The solution was then autoclaved for 30 minutes before pouring the cooling agar into sterile plastic petri dishes (3 ml) in a sterile environment cabinet. Seeds were placed

in a muslin cloth bag and surface sterilised in a 1% NaOCl solution for 5 minutes, followed by a thorough rinsing in running water for 3 minutes and then placed on a paper towel to remove excess moisture. Five seeds per plate (10 plates) for each sample of the four replicates of each seed treatment were aseptically plated on to PDA, embryo down. The seeds were then incubated at 25°C for five days, and fusarium identified and recorded (Booth, 1971; Hussein, 1987 and Kabeere, 1995) based on both colony and conidial characteristics using the microscope and the compound microscope, respectively. Quantifying was made by counting the number of seeds infected by a particular fungus and expressing as a percentage.(ISTA, 1993.)

3.3 Cracking/Damage tests

3.3.1 X-ray radiography was used to assess seed quality (Hill and Hill, 1994). The procedure for using the Hewlett-Packard Faxitron Model 43804N X-ray (see Plate 5) is as follows:

1. Place film on glass plate with letters '55' upwards.
2. Put seeds on top of film (embryo on film)
 - 3 rows of 10 machine harvested seeds
 - 2 rows of 10 hand harvested seeds
3. Put glass plate inside X-ray machine set at 30 KVP for 2½ minutes
4. Remove glass plate from machine
5. Place seeds on germination roll paper in the same order in which they were X-rayed. (positional germination)
6. Germinate rolls at 25°C (7 days)

7. Process film using the Polaroid Land Film Hold

L = insert film

P = withdraw film

8. Wait 60 seconds

9. Pull film apart

10. Compare appearance of seed (to detect mechanical damage such as internal cracking and embryo disorientation, and to detect damage caused by pests and pathogens) on X-ray film with seed germination results (see Plate 4A.,4B.)

3.3.2 Ferric Chloride Test

To determine the extent of mechanical damage to seeds, the ferric chloride test was carried out. Using the method of Duangpathra (1986), two replicates of 100 seeds were soaked in 20% ferric chloride solution made by adding 4 parts distilled water to 1 part FeCl_3 by weight for 25 minutes. The damaged seeds were determined by counting the black stained seeds (Plate 6, the back staining on the testa indicate the sites of mechanical damage penetrated by the salt which is subsequently oxidised (Sakunnarak,1992).) and the results are expressed as a percentage.

3.4 Vigour Tests

3.4.1 Seedling Growth Rate

This test was conducted on four replicates of 25 seeds. In preparing the To substratum, a line was drawn at the centre of the long axis of the germination paper

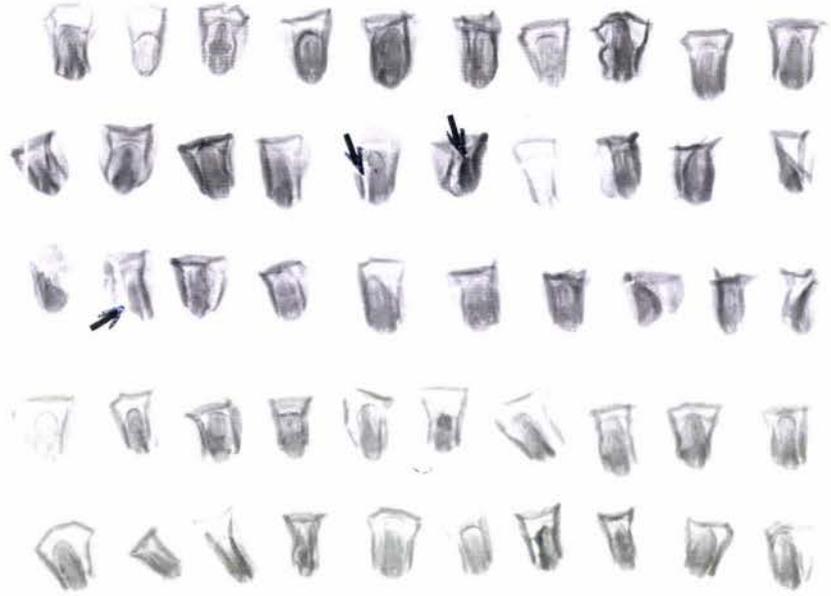


Plate 4A. X-ray photograph of machine threshed (m) (top 3 rows) & hand shelled (H) (bottom 2 rows) super sweetcorn seed showing damage seeds (→)



Plate 4B. Positional germination of seeds from Plate 4A showing differences in germination capacity



Plate 5. Faxitron Cabinet X-ray System Model 43804



Plate 6. Examples of surface cracking (→) following mechanical damage as shown by the ferric chloride test

and then the seeds of each replicate were spaced evenly along the centre line oriented with the embryo side up. The seeds were incubated at 25° c for 7 days (AOSA, 1983). Seedling growth was recorded by measuring shoot length and root and shoot dry weight of normal seedlings at 7 days after the start of the standard germination test at 25°C . Length of individual shoots were measured and mean length calculated using the formula:

$$L = \frac{\sum(X_i * n_i)}{N}$$

where N is the number of normal germinated seedlings and n is the number of normal seedlings whose coleoptile terminate in the mid point X_i . Results were expressed as shoot length per normal seedling. Shoot and root dry weights were determined separately by removing the shoot and root from normal seedlings, putting them separately into paper bag and drying at 80°C for 96 h to constant dry weight. Result were expressed as dry weight per normal seedling.

3.4.2 Conductivity Test

The conductivity test provides a measurement of electrolyte leakage from the seed. Conductivity measurement of the water in which a bulk sample (50 seeds) has been steeped identifies seed lots that have high laboratory germination, but may have poor field emergence potential.

Four subsample of 50 seeds were drawn at random and weighed to two decimal places (0.01g.) prior to placement in 500 ml flasks containing 250 ml of deionized water (50 seeds per flask). All flasks containing water and seeds were covered with aluminum foil prior to placing in a controlled temperature room at 20°C (± 1 c) for 24 hours. The conductivity meter must be turned on at least 15 minutes

prior to testing. At the end of the 24 hour soak period, the conductivity of the solution was measured immediately using the conductivity meter (CDM-83 Radiometer). The solution was swirled 10-15 seconds before each measurement (see Plate 13, 14). The conductivity results were expressed in micro siemens per gram of seed ($\mu\text{s/cm./gm.seed}$). The dip cell was rinsed in distilled water after measurement of each sample. The conductivity reading of sample was then subtracted from the conductivity reading of distilled water as a control and used to calculate the conductivity value. The conductivity reading of distilled water must be checked to ensure it was less than the prescribed maximum of 5 $\mu\text{s/cm./gm}$.

The conductivity per gram of seed weight for each subsample was calculated:

$$\frac{\text{conductivity}(\mu\text{s}) \text{ for each flask}}{\text{weight}(\text{g}) \text{ of dry seed sample}} = \mu\text{S cm}^{-1}\text{g}^{-1}$$

3.4.3 Accelerated Ageing Testing

According to the method of Hampton (1995) 40g. of super sweetcorn, seeds were weighed. Forty ml distilled water was placed in a 11x11x35 cm. plastic box, and then a 10 x10x3 cm. wire mesh screen put into the box, ensuring that the screen was above water level. The seed was then placed in approximately a single layer onto the wire screen. The box was then covered by a lid and placed on the upper and middle shelf of a germinator (Plate 12), running at 42°C for 96 h. After ageing, 4 replicates of 50 aged seeds were tested germination according to the ISTA Rules for Seed Testing (ISTA, 1993), as previously described. Because it is necessary to ensure that seeds for the germination test do not exceed 30 %SMC, the SMC of the seed sample after ageing was determined using 10 grams of super sweetcorn seed for each

sample according to the ISTA rules (ISTA, 1993). The results were then compared with the results of the germination of unaged seeds.

3.5 Seed Protein Test

The crude protein content (measured as nitrogen) in the maize grain sample is generally determined by the classical Kjeldhal analysis (Rasper, 1987). In this experiment the N content of the grain of the grain samples was determined by the macro Kjeldhal digestion method (AACC, 1983). In this method the protein nitrogen and other compounds react with boiling concentrated sulphuric acid. The acid mixture is then cooled, diluted with distilled water, and made strongly basic with sodium hydroxide. The ammonia is released and distilled into a boric solution. The ammonia in the boric acid solution is titrated with standardized hydrochloric acid using a Tecator Kjeltac auto 1030 analyzer. From the quantity of unrevealed acid determined by titration, the quantity of released nitrogen is established for each sample and subsequently converted to crude protein percentage (AOAC 1984).

From each plot sample approximately 10 g of grain was taken at random. All samples were then ground in a "Glen Creston" hammer mill until all grain passed through a 1 mm. sieve and collected in the collection tube. Crushed samples were mixed and up to 0.2 gm of sample weighed in duplicate and put in the digestion tube along with a "Kjel tablet" for the digestion process. 10ml of concentrated sulphuric acid was poured into the sample and mixed gently by swirling until the sample became clear and colourless and then kept to cool down. Thereafter 30 ml of distilled water was mixed into the sample and made compatible for analysis. Before starting the analysis a blank sample of distilled water and a standard sample of ammonium

iron (II) sulphate hexahydrate GR containing 7.145 %N was used to set the analyzer correctly for each batch.

All nitrogen contents were reported on a dry matter basis and converted protein content, using the conversion factor of 6.25 (AACC,1983) and then adjusted to 14% moisture content.

3.6 Data analysis: Analysis of variance

Statistical Analytical Systems (SAS,1991) were used for all statistical procedures. Several models of analysis of variance (ANOVA) were employed because different characters had different data structure. Least significance differences (LSD) and T-tests were used to compare and distinguish the means.

CHAPTER 4 RESULTS

Results

4.1 Seed quality determination

4.1.1 Standard tests

4.1.1.1 Germination

Germination was low for each harvest (Table 1) because of the high percentage of abnormal seedlings (Plate 8) and dead seed. Germination (% normal seedlings) did not differ between the 35% and 25% SMC harvests, or the 25% and 15% SMC harvests, but was significantly lower at the 15% SMC harvest than the 35% SMC harvest but non significant increases in abnormal seedlings and dead seeds (Table 1). Germination was significantly greater for hand-harvested seed (Table 2, Plate 7) because of a reduction in the percentage of abnormal seedlings and dead seeds compared with that for machine-harvesting (Table 2). There was an interaction between seed moisture content at harvest and method of harvest for normal seedlings (Table 3) because machine harvesting at the two high seed moisture contents reduced the percentage of normal seedlings compared with hand harvesting at these seed moisture contents. In contrast, there were no interaction for the percentage of abnormal seedlings or dead seeds (Table 3).

Neither nitrogen application or fungicide had any effect on normal and abnormal seedlings and dead seeds. There were no significant interactions among seed moisture content, method of harvest, nitrogen or fungicide for any of these germination parameters.

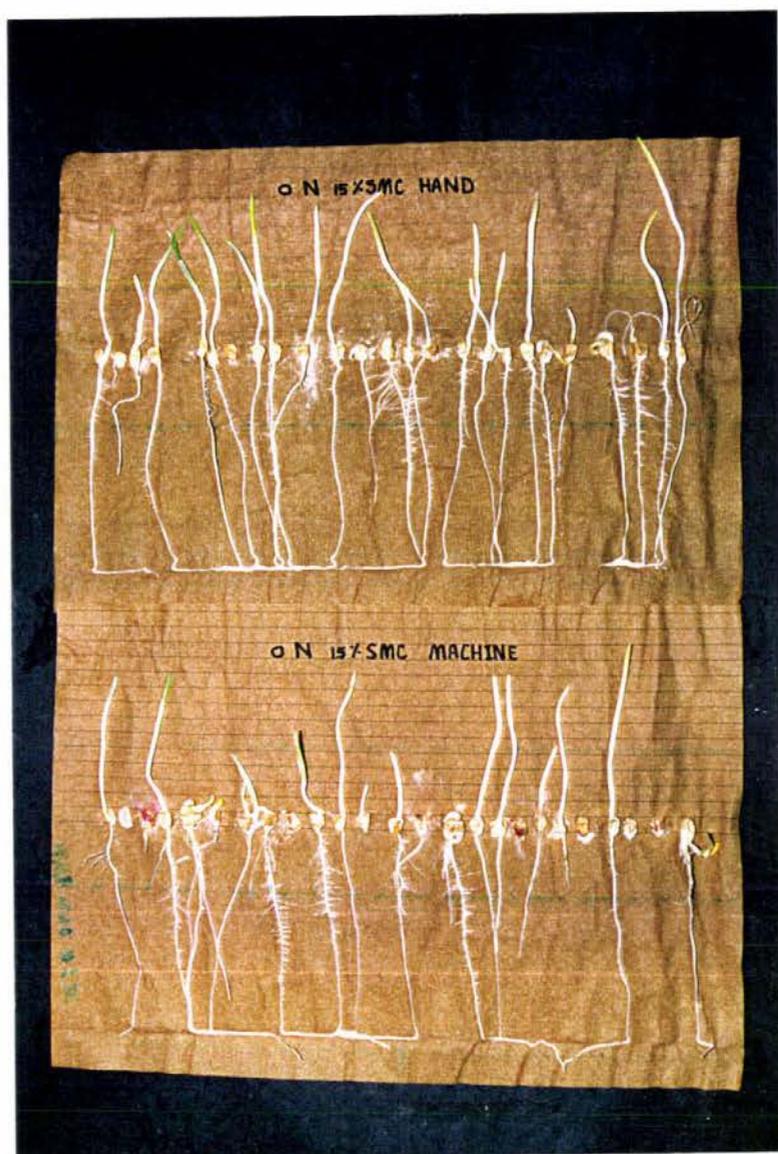


Plate 7. Germination of seed harvested at 15% SMC by hand (top) and by machine (bottom)

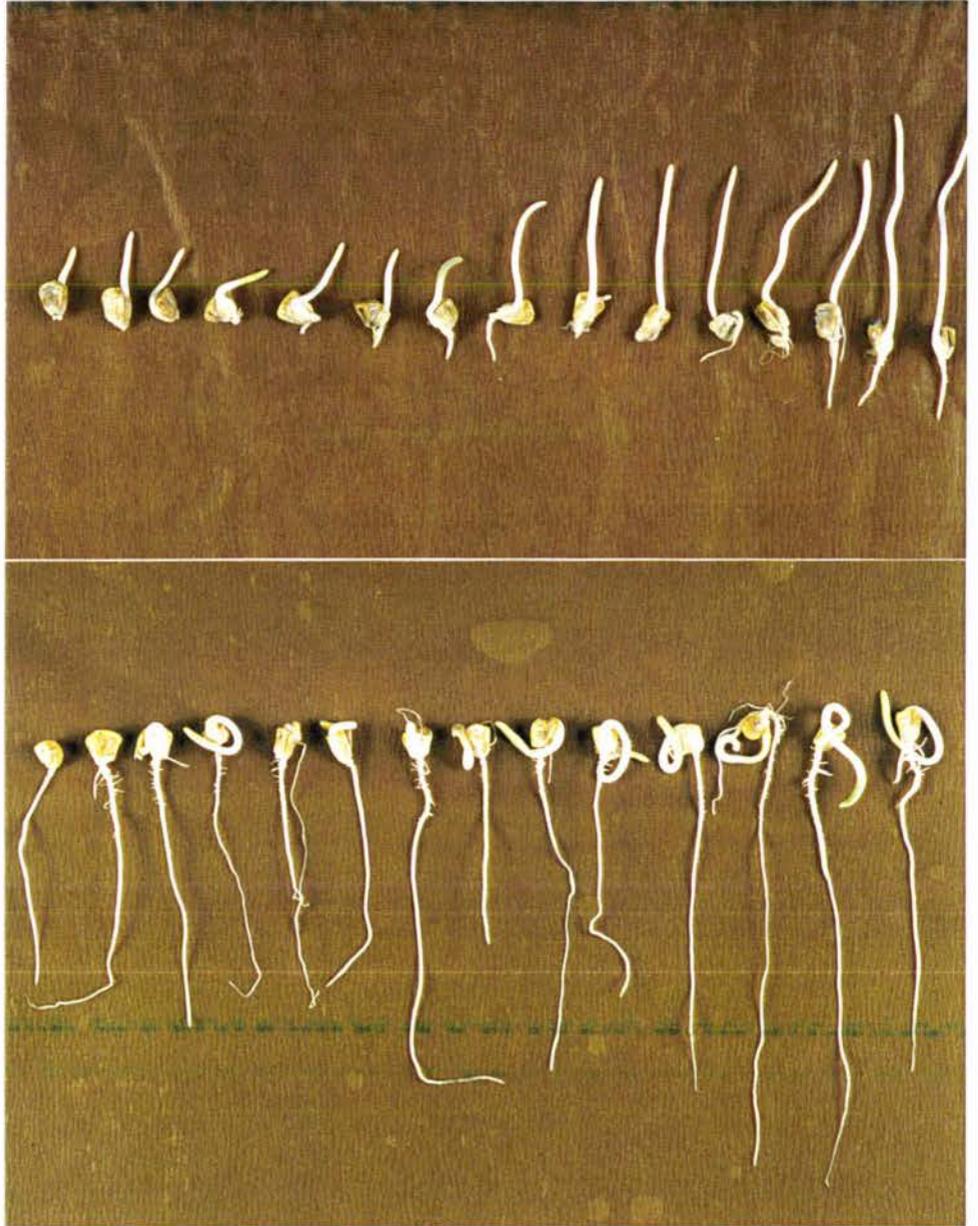


Plate 8. Examples of abnormal seedlings for machine harvested seeds

Table 1. Effect of seed moisture content at harvest on seed germination.

Seed moisture content	Normal seedlings (%)	Abnormal seedlings (%)	Dead seeds(%)
35 %	58.5 ^a	24.6 ^a	16.9 ^a
25 %	57.1 ^{ab}	25.2 ^a	17.7 ^a
15 %	53.4 ^b	26.9 ^a	19.6 ^a
LSD (P<0.05)	3.98	NS	NS

Results followed by the same letter superscript are not significantly different at the P<0.05 level (applies to all tables).

Table 2 Effect of method of harvest on seed germination.

Harvest method	Normal seedlings %	Abnormal seedlings %	Dead seeds %
Hand harvest	62.6 ^a	24.0 ^b	13.4 ^b
Machine harvest	50.1 ^b	27.0 ^a	22.9 ^a
LSD (P<0.05)	3.87	2.63	2.50

Table 3. Interaction between seed moisture content at harvest and method of harvest for standard germination .

Seed moisture content	Normal seedlings (%)		Abnormal seedlings (%)		Dead seeds (%)	
	Hand	Machine	Hand	Machine	Hand	Machine
35%	68.2 ^a	48.9 ^c	21.0	28.1	10.8	23.0
25%	60.9 ^b	53.3 ^c	25.0	25.3	14.1	21.4
15%	58.6 ^{bc}	48.0 ^c	25.9	28.0	15.5	24.0
LSD (P<0.05)	5.62		NS		NS	

4.1.1.2 Thousand seed weight

Nitrogen application significantly increased thousand seed weight, (Table 4). Nitrogen applied at 100 and 200 kg /ha produced seeds with similar thousand seed weights (142.6 and 145.5 respectively). Fungicide application, method of harvest and seed moisture content did not affect thousand seed weight, and there were no significant interactions.

Table 4. Effect of nitrogen application on thousand seed weight

Nitrogen application	Thousand seed weight
0 kg N/ha	133.4 ^b
100 kg N/ha	142.6 ^a
200 kg N/ha	145.5 ^a
LSD (P<0.05)	3.36

4.1.1.3 Seed Health

Fusarium infection of seed increased as harvest was delayed (Table 5), with seed harvested at 15% SMC having the highest infection level (83.4%). Seed harvested at 25% SMC and 35% SMC did not differ in infection level. This increase was primarily due to the machine harvest method (Table 6), as the incidence was significantly greater for this method at the last harvest.

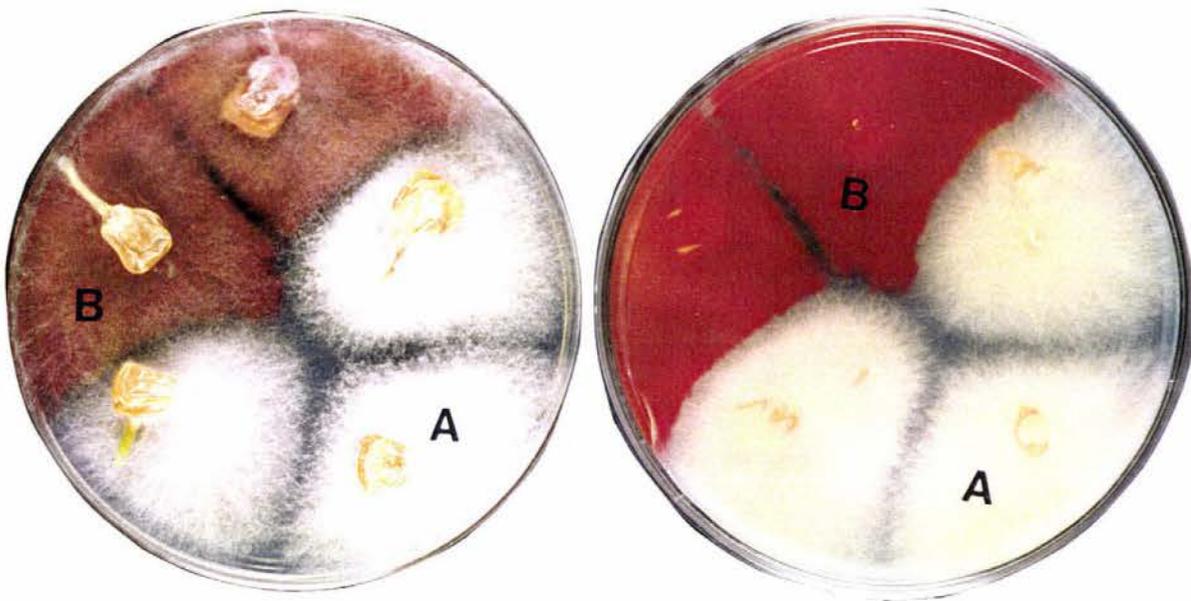
Table 5. Effect of seed moisture content at harvest on the percentage of seeds of super sweetcorn infected with *Fusarium* spp.

Seed moisture content at harvest	% Seeds infected
35 %	76.6 ^b
25 %	77.3 ^b
15 %	83.4 ^a
LSD (P<0.05)	4.76

* see Plates 9,10 and 11



Plate 9. Seed and cob rots resulting from fungal infection



Top view

Reverse side

Plate 10. A = *F. subglutinans* : conony morphology on PDA Colony with white powdery surface, reverse with creamy pigmentation

B = *F. graminearum* : red-brown and fluffy, reverse with red pigmentation



Top view

Reverse side

Plate 11. A = *F. poae* : conony morphology on PDA
Colony with white cottony surface, reverse
with burgundy pigmentation

Table 6. Interaction between seed moisture content at harvest and harvest method on the percentage of seeds infected with *Fusarium* spp.

Seed moisture content at harvest	% Seed infected	
	Harvest method	
	Hand	Machine
35 %	78.6 ^b	74.5 ^b
25 %	76.7 ^b	77.9 ^b
15 %	78.8 ^b	87.9 ^a
LSD (P<0.05)	6.75	

There was also an interaction between nitrogen application levels and fungicide application on the incidence of *Fusarium* in super sweetcorn seed, as shown in Table 7

The percentage of seeds infected was lowest in super sweetcorn treated with 0 kgN/ha plus fungicide. However, fungicide application did not decrease the incidence of fungal infection in seed to which nitrogen was applied. In the absence of fungicide, there were no significance differences in the percentage of seeds infected at any level of applied nitrogen.

Table 7 Interaction between nitrogen application levels and fungicide application for the percentage of seeds infected by *Fusarium* spp.

Nitrogen Application	% Seeds infected	
	Fungicide	
	- F	+ F
0 kgN/ha	79.8 ^{ab}	73.7 ^b
100 kgN/ha	75.3 ^{ab}	82.1 ^a
200 kgN/ha	81.9 ^a	81.7 ^a
LSD (P<0.05)	7.00	

4.2 Cracking/damage tests

4.2.1 Ferric chloride (FeCl₃) test

Nitrogen application had no significant effect on the percentage of mechanically damaged machine harvest seed (Table 8). However, machine harvested seed had a greater percentage of mechanically damaged seed (28.3%) than hand-harvested seed (13.1% ;Table 8).

Delaying seed harvest increased the percentage of mechanically damaged seed (Table 9). Seed harvested at 15% seed moisture content had the highest percentage of seed with mechanical damage (26.6%), whereas harvesting at 35% seed moisture content produced the lowest percentage of seed with mechanical damage (23.4%), which did not differ significantly from harvesting at 25% seed moisture content (24.8%).

There were no significant interactions among method of harvest and seed moisture content for mechanically damaged seed.

Table 8. Effect of nitrogen application levels and method of harvest on the percentage of mechanically damaged seed.

Treatment	% Mechanical damage seed
0 N,no Fungicide,Machine	28.3 ^a
100 N,no Fungicide,Machine	29.2 ^a
200 N,no Fungicide,Machine	29.3 ^a
0 N,no Fungicide,Hand	13.1 ^b
LSD (P<0.05)	2.28

Table 9 Effect of seed moisture content at harvest on the percentage of mechanically damaged seed.

Seed moisture content	% Mechanical damage seeds
35% SMC	23.4 ^b
25% SMC	24.8 ^b
15% SMC	26.6 ^a
LSD (P<0.05)	1.97

4.3 VIGOUR TESTS

4.3.1 Seedling growth test

Hand harvested seed had a significantly ($P<0.05$) higher seedling shoot length, shoot weight and root weight than machine harvested seed (Table 10). Neither nitrogen application nor fungicide had any effect on seedling shoot length, shoot weight or root weight.

Table 10. Effect of harvest methods on seedling shoot length, shoot weight and root weight.

Harvest method	Shoot length (cm)	Shoot weight (g)	Root weight (g)
Hand	5.83 ^a	0.84 ^a	0.23 ^a
Machine	4.56 ^b	0.64 ^b	0.16 ^b
LSD (P<0.05)	0.45	0.06	0.02

Delaying harvest reduced seedling shoot and root weight (Table 11) but not shoot length (data not presented). Seedling performance did not differ for the 35 and 25% SMC harvest, but was significantly lower for the 15% SMC harvest (Table 11)

Table 11. Effect of seed moisture content at harvest on seedling shoot and root weight.

Seed moisture content at harvest	Shoot weight (g)	Root weight (g)
35 %	0.81 ^a	0.21 ^a
25 %	0.77 ^a	0.20 ^a
15 %	0.63 ^b	0.17 ^b
LSD (P<0.05)	0.07	0.02

Hand harvesting at 35% SMC produced seedlings with the highest shoot weight (0.98g) and root weight (0.28g)(Table 12). In contrast, machine harvesting at 15% SMC produced seedlings with the lowest shoot weight (0.55g) and root weight (0.16g). All levels of seed moisture content with hand harvesting had significantly higher ($P<0.05$) seedling shoot weight and root weight than seedlings from machine harvested seeds.

Table 12 Interaction between seed moisture content at harvest and harvest method for seedling shoot and root weight.

Seed moisture content at harvest	Shoot weight (g)		Root weight (g)	
	Harvest method		Harvest method	
	Hand	Machine	Hand	Machine
35 %	0.98 ^a	0.64 ^{cd}	0.28 ^a	0.16 ^d
25 %	0.81 ^b	0.73 ^{bc}	0.23 ^b	0.19 ^{cd}
15 %	0.72 ^{bc}	0.55 ^d	0.20 ^{bc}	0.16 ^d
LSD (P<0.05)	0.11		0.03	

4.3.2 Electroconductivity

Conductivity (Plate 13,14) was significantly greater for machine (12.31 $\mu\text{S/cm/g}$) than hand harvested seed (7.56 $\mu\text{S/cm/g}$) (Table 13). Seed harvested at 15% SMC had the highest conductivity (10.67 $\mu\text{S/cm/g}$), which was significantly greater than that for seed harvested at 25% SMC and 35% SMC (9.85 and 9.29 $\mu\text{S/cm/g}$; Table 14).

There was an interaction between nitrogen application levels, seed moisture content at harvest and fungicide for electroconductivity of super sweetcorn seeds (Table 15). The reason for this significant interaction was because of the significant reduction in the conductivity value of seeds from the no-nitrogen treatment only harvested at 25% and 35% seed moisture content when treated with fungicide. By comparison, there was no significant effect of fungicide on electroconductivity when seed was harvested at 15% seed moisture content from the no-nitrogen treatment, nor at any nitrogen level.

Table 13. Effect of harvest method on electroconductivity of super sweetcorn seeds.

Harvest method	Conductivity ($\mu\text{S}/\text{cm}/\text{g}$)
Machine	12.31 ^a
Hand	7.56 ^b
LSD (P<0.05)	0.56

Table 14. Effect of seed moisture content at harvest on electroconductivity of super sweetcorn seeds.

Seed moisture content	Conductivity ($\mu\text{S}/\text{cm}/\text{g}$)
35 %	9.29 ^b
25 %	9.85 ^b
15 %	10.67 ^a
LSD (P<0.05)	0.68



Plate 12. A germinator with wire-mesh baskets in plastic box onto shelves before accelerated ageing



Plate 13. Conductivity test



Plate 14. Conductivity Metre (CDM-83 Radiometre)

Table 15. Interaction between nitrogen application levels, seed moisture content at harvest and fungicide for seed electroconductivity.

Nitrogen Application Level	Conductivity ($\mu\text{S}/\text{cm}/\text{g}$)					
	15 % SMC		25 % SMC		35 % SMC	
	- F	+ F	- F	+ F	- F	+ F
0kgN/ha	10.63 ^{abc}	10.21 ^{abcd}	11.87 ^a	8.45 ^{ef}	9.99 ^{bcde}	7.68 ^f
100kgN/ha	11.67 ^{ab}	10.57 ^{abc}	10.85 ^{abc}	10.02 ^{bcde}	9.08 ^{cde}	9.65 ^{cde}
200kgN/ha	10.56 ^{abc}	10.40 ^{abcd}	10.34 ^{abcd}	10.05 ^{bcde}	9.28 ^{cde}	9.57 ^{cde}
LSD (P<0.05)	1.68					

4.3.3 Accelerated Ageing

The effect of harvest method on normal and abnormal seedlings, and dead seed, before and after accelerated ageing (Plate 12) are shown in Table 16. Hand harvesting produced a higher percentage of normal seedlings and a lower percentage of abnormal seedlings and dead seeds than machine harvesting.

Table 17 presents the effects of seed moisture content at harvest on the percentage of normal, abnormal seedlings and dead seed before and after accelerated ageing. Before accelerated ageing the percentage of normal seedlings did not differ for seed harvested at 35% and 25% SMC, but was significantly lower for seed harvested at 15% SMC. After accelerated ageing the normal seedling percentage did not differ for seed harvested at 35% and 15% SMC, but was significantly lower for seed harvested at 25% SMC.

In terms of abnormal seedlings the percentage recorded before accelerated ageing did not differ significantly at any seed moisture content. However, after accelerated ageing seed harvested at 25% SMC had the highest percentage of abnormal seedlings

(14.1), which was significantly greater than that for seed harvested at 35% and 15% SMC (12.6 and 12.3). Before accelerated ageing the percentage of dead seeds did not differ for seed harvested at 15% and 25% SMC, but was significantly lower for seed harvested at 35% SMC. After accelerated ageing the dead seeds percentage did not differ for seed harvested at 15% and 25% SMC, but was significantly lower for seed harvested at 35% SMC.

Table 16. Effect of harvest method on normal seedlings, abnormal seedlings and dead seeds before and after accelerated ageing.

Harvest method	% Normal seedlings		% Abnormal seedlings		% Dead seeds	
	Before AA	After AA	Before AA	After AA	Before AA	After AA
Hand	62.6 ^a	77.8 ^a	24.0 ^b	9.8 ^b	13.4 ^b	12.4 ^b
Machine	50.1 ^b	58.2 ^b	27.0 ^a	16.4 ^a	22.9 ^a	25.4 ^a
LSD(P<0.05)	3.87	1.89	2.63	1.16	2.50	1.29

Table 17. Effect of seed moisture content at harvest on the percentage of normal, abnormal seedlings and dead seeds before and after accelerated ageing.

Seed moisture content at harvest	% Normal seedlings		% Abnormal seedlings		% Dead Seeds	
	Before AA	After AA	Before AA	After AA	Before AA	After AA
35%	58.5 ^a	69.9 ^a	20.5 ^a	12.6 ^b	21.0 ^b	17.5 ^b
25%	57.1 ^{ab}	66.2 ^b	17.8 ^a	14.1 ^a	25.1 ^a	19.7 ^a
15%	53.4 ^b	68.0 ^{ab}	18.4 ^a	12.3 ^b	28.2 ^a	19.7 ^a
LSD (P<0.05)	3.98	2.47	3.20	1.40	3.30	1.35

Table 18. Interaction between seed moisture content at harvest and method of harvest for germination after accelerated ageing.

Seed moisture content at harvest	% normal seedlings		%Abnormal seedlings		% Dead seeds	
	Hand	Machine	Hand	Machine	Hand	Machine
35 %	83.0 ^a	56.5 ^d	7.0 ^d	17.5 ^a	10.0 ^c	26.0 ^a
25 %	75.0 ^b	57.5 ^{cd}	11.3 ^c	17.0 ^a	13.7 ^b	25.5 ^a
15 %	75.3 ^b	60.6 ^c	10.3 ^c	14.3 ^b	14.4 ^b	25.1 ^a
LSD (P<0.05)	3.5		2.0		2.6	

Table 18 shows that the percentage of normal seedlings after accelerated ageing was significantly higher when hand harvested than when machine harvested at all seed moisture contents. However, the difference was greatest at 35% SMC

because the percentage of normal seedlings when hand harvested was significantly greater at 35% SMC than at 25% and 15% SMC. With the machine harvest, this trend was reversed, with the percentage of normal seedlings being significantly higher at 15% SMC than at 35% SMC.

In terms of the percentage of abnormal seedlings recorded after accelerated ageing, the results were largely a reversal of the figure for normal seedlings viz the percentage of abnormal seedlings was greater when machine harvested than when hand harvested; lower at 35% SMC than at 25% and 15% SMC when hand harvested; and lower at 15% than at 25% and 35% SMC when machine harvested.

The percentage of dead seeds recorded after accelerated ageing, also showed that machine harvesting was significantly more damaging than hand harvesting. Also, that hand harvesting at 15% and 25% SMC resulted in a higher percentage of dead seed than at 35% SMC, but when machine harvested all seed moisture contents showed a very similar and relatively high percentage of dead seeds.

Nitrogen application had no effect on normal seedlings and abnormal seedlings

Table 19. Interaction between seed moisture content at harvest, harvest method and fungicide on normal seedlings (seed vigour) after accelerated ageing.

Seed moisture content at harvest	% Normal seedlings after Accelerated Ageing			
	Hand		Machine	
	- Fungicide	+ Fungicide	- Fungicide	+ Fungicide
35 %	83.1 ^a	83.3 ^a	53.3 ^e	59.8 ^{cd}
25 %	74.6 ^b	75.3 ^b	55.8 ^{de}	59.0 ^{cd}
15 %	76.1 ^b	74.5 ^b	58.5 ^{cd}	62.8 ^c
LSD (P<0.05) = 4.94				

The percentage of normal seedlings after accelerated ageing was significantly higher when hand harvested than when machine harvested at all seed moisture contents (Table 19). Fungicide had no effect on normal seedlings when hand harvested but tended to increase the percentage of normal seedlings when machine harvested, particularly at 35% SMC.

4.4 Determination of seed nitrogen

The effect of nitrogen application levels on nitrogen content of seed machine harvested at 15% seed moisture content is shown in Table 20. The percentage nitrogen content of the seed increased as nitrogen application level increased, from 2.48% N when no nitrogen was applied to 2.69% N when nitrogen was applied at 200kg N/ha. However, there was no difference between 200 kg N/ha and 100 kg N/ha.

Table 20. Effect of nitrogen application levels on nitrogen content of seed machine harvested at 15% seed moisture content.

Nitrogen Application Levels	% N of seed harvested
0 kg N/ha	2.48 ^b
100 kg N/ha	2.63 ^a
200 kg N/ha	2.69 ^a
LSD (P<0.05)	0.08

DISCUSSION AND CONCLUSIONS

This study demonstrated the dramatic effect that seed-borne pathogens can have on seed quality (Neergaard, 1977). *Fusarium* fungi were recovered from between 75-88% of seeds, depending on harvest time. This infection level was similar to that previously reported by Hampton et al (1994) from the same cultivar following a November sowing date at the same site. These authors found that *F. graminearum* (Schwabe) was the species most commonly detected in super sweet corn seed lots, followed by *F. subglutinans* (Wollenw. and Reinking), *F. poae* (Peck) Wollenw. and other unidentified *Fusarium* species. The *Fusaria* were not identified to species level in this study, but the results of Hampton et al (1994) and Kabeere (1995) for maize grown at the same site would strongly suggest that *F. graminearum* and *F. subglutinans* were also the most prevalent species.

Both *F. graminearum* and *F. subglutinans* are important pathogens of *Zea mays* (Kabeere, 1995). *F. subglutinans* has been previously reported to substantially reduce germination (Gilbertson et al, 1985), while the seed-borne phase of *F. graminearum* produces seedling blights (Cooke, 1968) and may also reduce germination (Kabeere, 1995). The high percentages of abnormal seedlings (25%) and dead seeds (18%) recorded from this experiment were mostly a result of *Fusarium* seed infection, as most abnormal seedlings were classified as such because of fungal damage (ISTA, 1993), while dead seeds often showed the characteristic pink/red mycelial growth on the germination substrate which is associated with *Fusarium* infection (Kabeere, 1995). A further indicator of the effect of *Fusarium* was provided by the accelerated ageing vigour test results, where germination after AA was greater (but not always significantly so) than germination before AA. Normally, germination results after AA are either similar or up to 10% lower than germination results before AA (if the seed lot is of high vigour), or significantly reduced (if the seed lot is of low vigour) (see Hampton and TeKrony, 1995). The reduction in abnormal seedlings after AA compared with before AA strongly suggests that *Fusarium* fungi were less active, and Mashauri (1993) showed that temperatures of 40-45° for up to 96h reduced the *Fusarium* content of super-sweet corn seed lots.

Cobs in the field were subjected to weathering damage as seeds dried down, and were also attacked by birds who exposed the tips of the cobs to the environment. Any sort of injury to the plant/cob can facilitate infection of plant tissue by fungal inoculum. However for the *Fusarium* fungi, there are a number of possible pathways for infection. Invasion of the vascular parenchyma can occur because air-borne *Fusarium* spores frequently lodge between the leaf sheath and the leaf stalk, an area which provides favourable conditions for the spore to germinate and penetrate into the main stalk. *Fusarium* fungi may also enter in the region of the silks, and then spread to bracts and pedicels through the vascular cylinder and finally to the shank (Koehler, 1942). Which of these infection pathways occurred in this trial is not known.

Fusarium infection levels increased slightly as harvest was delayed, which is consistent with greater time available for colonization (Sutton, 1982), and results previously reported for maize at the same site (Kabeere, 1995). Harvest method did not affect *Fusarium* levels, except at the 15% SMC harvest where levels in machine harvested seed were significantly greater than for hand harvested seed, possibly because the former harvest method distributed inoculum to a greater extent within the seed lot. Statistically, there was a significant effect of nitrogen on *Fusarium* infection, in that in the presence of fungicide, the seed-borne inoculum level was lower at zero nitrogen than for the 100 and 200 kg N/ha application levels. Jones and Clifford (1983) noted that seeds with higher protein levels were more prone to pathogen attack, but whether this is what occurred can not really be substantiated, particularly as this effect did not show up in the absence of fungicide.

The surprising result was that application of the fungicide Sportak had no effect on the levels of seed-borne *Fusarium*. This product has a label claim for control of *Fusarium* ear diseases in cereals. It is obvious that the three applications were not sufficient, and that fungicide application should have continued at possibly fortnightly intervals until each harvest. This aspect of this work requires further study, because it is evident that it will not be possible to produce quality super-sweet corn seed unless *Fusarium* fungi can be controlled in the seed production field.

The low starch levels in super sweet corn result in a severely collapsed endosperm and

cracked pericarp (Styer and Cantliffe, 1984) while the high sugar content elevates osmotic potential which may cause cell membrane and pericarp damage (Headrick et al, 1990). This physical and physiological damage is associated with the often poor seed quality of super-sweet corn (Jovic et al, 1993).

The structural integrity of cell membranes (which depends on the stability of phospholipids and protein molecules; Bewley, 1986) acts as a selectively permeable barrier controlling the general diffusion of materials into and out of the cells. It is also important for many biochemical reactions essential for the physiology of living cells, and hence the seed's potential performance (AOSA, 1983). Membrane damage is likely to be the most important cause of the loss of vigour and viability seeds experience as they age (Powell, 1988). Nitrogen fertiliser application can increase protein content in cereal crops (Bulisanai and Warner, 1980), and seeds with higher protein levels outperform low protein seeds of the same cultivar (Mashauri, 1993). High positive correlations have been reported between high protein content and seedling vigour (Ries and Everson, 1973), and there are limited data to suggest that nitrogen and/or phosphorous supplies to the mother plant may increase seed vigour (Hadavizadeh and George, 1988), because deficiencies in these elements may affect membrane permeability (and hence vigour) through the effects on protein and phospholipid components of the membranes.

Increasing the nitrogen fertiliser application rate increased the thousand seed weight and the nitrogen content of the harvested seed, but no significant interactions between nitrogen application rate and indices of seed vigour were recorded. For example, if the hypothesis regarding seed vigour and nitrogen supply was to be substantiated, conductivity (as a measure of cell membrane integrity; Hampton and TeKrony 1995) should have reduced as nitrogen application rate increased. However, conductivity either did not differ significantly among nitrogen application rates, or was significantly lower for the no nitrogen treatment. Nitrogen had no significant effects on seedling shoot or root growth parameters or on accelerated ageing test results.

While these results were confounded by *Fusarium* infection, a repeat of this experiment should perhaps not just investigate the effects of nitrogen alone. Browning and George

(1981) reported that in garden peas, high nitrogen application levels decreased seed vigour, a result also reported by Hadvizadeh and George (1986). However, these latter authors also found that high nitrogen in combination with moderate levels of phosphorous increased pea seed vigour. This is obviously an area of research which requires more intensive study, both at the seed (*ie* vigour test) and cellular level.

When compared with hand harvesting, machine harvesting lowered germination because of a very small increase in the production of abnormal seedlings, and because of a nearly 50% increase in the percentage of dead seeds. This was presumably related to the increased percentage of mechanically damaged seeds, as revealed by the ferric chloride staining test. During machine harvesting, seeds are subject to both static and dynamic forces which can cause internal and external damage. Internal damage may be either stress cracks or disorganisation of the endosperm and/or embryo, while external damage can range from pieces of pericarp missing, through severe pericarp damage, open cracks in the endosperm or embryo disorientation, to chipped, crushed or broken seeds (Mashauri, 1991). For the machine harvest, around 29% of seeds showed mechanical damage. However, this does not necessarily always mean that germination will be reduced. Hampton et al (1994) reported over 50% mechanical damage in two seed lots of Illini Gold, but germination was 87%. Escasinas (1986) demonstrated that the extent of mechanical (or cracking) damage *per se* bears little relation to loss of germinability; rather, it is the position of the damage in relation to the embryo which is important. If cracks are situated either alongside or extending into the middle of the embryo, then germination will be severely reduced. Cracks outside the embryo are likely to have little effect on germination, but may offer an entrance for pathogens and/or storage fungi.

While the ferric chloride test detects physical cracking of the seed coat, disruption to the seed not visible to the naked eye may be just as, or more, important. For example, Mashauri et al (1992) observed after tetrazolium testing (ISTA, 1995) that bruised maize seeds with internal disruption had a more severe reduction in germination and vigour than cracked seeds. Bruising causes collapse of tissue and the release of hydrolytic enzymes which may subsequently do extensive damage to the seeds (O'Brien et al, 1984) and reduce germination and vigour as a result.

Seeds which are damaged but still viable may develop problems in the mobilisation of food reserves or growth metabolism, and are often more liable to imbibition damage, resulting in poor germinability (Simon and Mills, 1983). This occurs because cells near the site of external damage cannot cope with a rapid influx of water, and eventually burst or undergo autohydrolysis, thus losing their contents to the surrounding medium (Matthews and Powell, 1986) at higher rates than undamaged seeds (Bruggink et al, 1991).

Seedlots which have poor germination because of obvious seed deterioration would not be expected to be able to be stored successfully. However, seed lots with high (>90%) germination but small internal injuries will also tend to have a reduced storage potential, as seed deterioration is accelerated in such cases (Escasinas, 1986), resulting initially in increased seedling abnormalities, and eventually, death.

Because of its high sugar content, super sweet corn seed is more prone to injury during harvest and processing than maize. The concentrated sucrose solution in the endosperm resists drying (Wilson and Trawatha, 1991), slows the seed maturation process (Churchill and Andrew, 1983) and subjects the seeds to greater weathering and/or pathogen damage (Mashauri, 1993). Drying is therefore usually necessary, and seeds can be subjected to both physical and physiological damage during this process (Herter and Burris, 1989; Mashauri, 1993). In seeds of higher plants, raffinose-family oligosaccharides are believed to be a key factor in protecting membranes in dry seeds (Hoekistra et al, 1989). These sugars inhibit crystallisation of sucrose, allowing the formation of an H-bonding 'glass' which stabilises membrane structure in the dry seed (Koster and Leopold, 1988). Recent desiccation tolerance studies in maize have demonstrated that the ratio of sucrose to raffinose has been implicated as a factor in the development of drying tolerance in maize (Chen and Burris 1990; 1991). Wilson and Trewatha (1991) suggested that the *Sh₂* gene may interfere with raffinose synthesis directly, or might alter the raffinose/sucrose ratio by flooding the system with sucrose. Whatever the mechanism, super sweet corn requires delicate handling during harvest and processing.

Time of harvest can therefore significantly affect super sweet corn seed quality. If seed is harvested at 'high' seed moisture contents (40-50%; Wilson and Trawatha, 1991), it must be dried, and desiccation damage can be readily induced. Sweetcorn seeds are intolerant of high

drying rates caused by high temperatures (Schleppi and Burris, 1989), and to avoid loss of viability and vigour, drying should be slow and at a temperature of around 35°C (Wilson and Trawatha, 1991). Conversely, and as shown in this study, if seed is able to dry down naturally to around 15% SMC, quality is likely to be impaired through pathogen invasion and seed deterioration resulting from weathering (Delouche 1980; Hardacre et al, 1989, 1991).

In the Manawatu, maize growers are advised to harvest maize at around 22-25% SMC (Hardacre et al, 1991). While the reductions in seed quality resulting from delaying harvest until 15% SMC were evident, there was no advantage in harvesting earlier (*ie* at 35% SMC) for this trial, because seed quality did not differ for seed harvested at either 35% or 25% SMC. However, the harvested seeds were ambient air dried, and presumably with this slow natural drying method, drying injury would not have occurred. Drying damage (stress cracking; Escasinas 1986, or alternatively case hardening, Hill and Johnstone 1985) most commonly occurs as a result of high drying rates caused by the high temperature drying of wet seed. The effects of drying methods and rates on super sweet corn seed quality require further study.

The presence of *Fusarium* spp. in this field trial was expected, as Mashauri (1993) and Hampton et al (1994) had previously reported the seed quality problems in super sweet corn cv. Illini Gold caused by these fungi. What was not expected was the failure of the fungicide applications to exert any control of the *Fusarium* species. This meant that the objectives originally set for this trial could not be fulfilled. These results have however, demonstrated the influences of the many factors which can affect seed quality in super sweet corn. It is evident that control strategies for *Fusarium* spp, including effective seed treatment (Hampton et al, 1994), fungicide application at fortnightly intervals from tasselling through to harvest, and careful site selection must be determined and implemented, before more subtle factors such as those influencing seed vigour, can be investigated.

Conclusions

- 1 At this site, *Fusarium* fungi detrimentally affected seed quality by reducing germination.
- 2 While delaying harvest allowed increased *Fusarium* infection of seed, infection levels were high even at the 35% seed moisture content harvest.
- 3 Method of harvest did not affect *Fusarium* seed infection levels.
- 4 Sportak 45EC failed to control *Fusarium* spp. when applied as a foliar spray.
- 5 Nitrogen application increased thousand seed weight and seed nitrogen content, but no significant interactions between nitrogen application rate and indices of seed vigour were recorded. The *Fusarium* seed borne inoculate load may have masked any such interactions.
- 6 Machine harvesting decreased seed quality (increased seed cracking and decreased germination) when compared to hand harvesting incorporation of seed moisture content at harvest.
- 7 The failure of the fungicide to control *Fusarium* spp. meant that the original objectives could not be achieved. Effective control of *Fusarium* must be achieved before this trial could be repeated.

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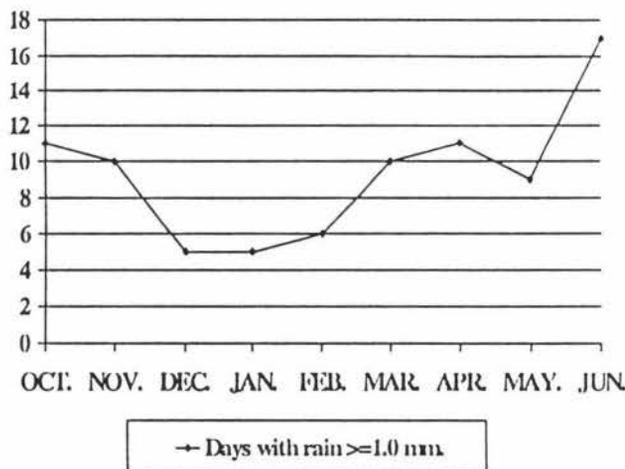
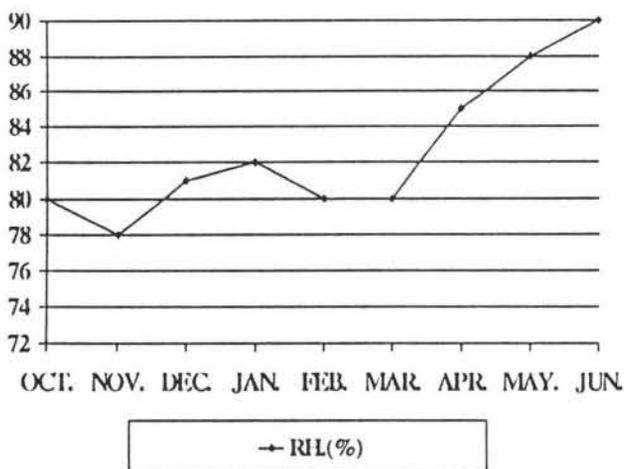
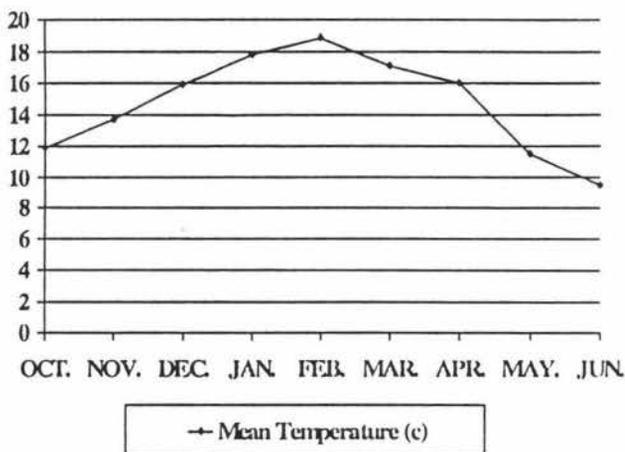
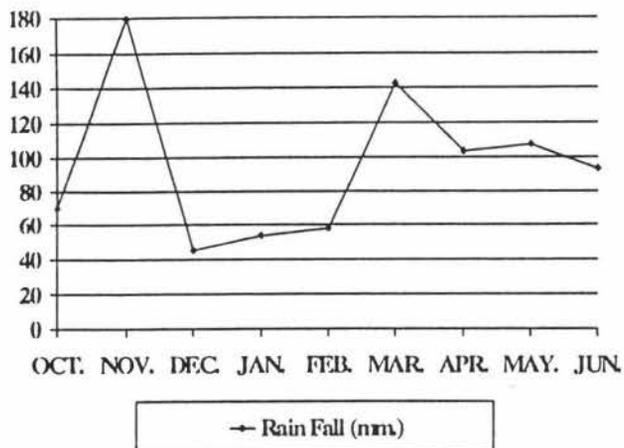
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APPENDICES

Appendix 1: Climate data (October '94-June '95)



Source: AgResearch Grasslands, Palmerston North, NZ.

% Fungi Infection, at 15% SMC

Treat.	Hand Harvest						Machine Harvest					
	- F			+ F			- F			+ F		
	F.g ram	F.s ub.	F.p oae	F.g ram	F.s ub	F.p oae	F.g ram	F.s ub	F.p oae	F.g ram	F.s ub	F.p oae
0	49	16	4	49	17	11	51	24	8	46	16	8
100	40	21	9	48	22	7	57	15	8	57	17	5
200	47	22	5	53	22	10	50	16	6	50	22	6

% Fungi infection, at 25% SMC

Treat.	Hand Harvest						Machine Harvest					
	- F			+ F			- F			+ F		
	F.g ram	F.s ub	F.p oae	F.g ram	F.s ub	F.p oae	F.g ram	F.s ub	F.p oae	F.g ram	F.s ub	F.p oae
N												
0	45	25	8	26	17	10	45	19	8	40	22	10
100	32	28	6	48	15	10	40	18	15	50	15	9
200	52	20	12	38	30	9	58	16	10	52	15	10

% Fungi Infection , at 35% SMC

Treat.	Hand Harvest						machine Harvest					
	- F			+ F			- F			+ F		
	F.g ra	F.s ub	F.p oae	F.g ru	F.s ub	F.p oae	F.g ra	F.s ub	F.p oae	F.g ra	F.s ub	F.p oae
0	38	23	5	43	15	8	34	21	15	40	18	5
100	49	15	8	41	16	8	39	22	8	45	25	6
200	53	19	11	54	12	9	38	39	12	38	28	34