University of Alberta

Agronomic Evaluation Of Early Maturing Silage Maize Hybrids In Central Alberta

by

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Abstract

Maize (*Zea mays L.*) hybrids developed for short season environments (2000-2200 Corn Heat Units [CHU]) may be capable of achieving silage maturity in central Alberta. In one experiment at seven locations, increasing plant density from ~50 000 to ~124 000 plants/ha^{-1} delayed silk emergence 5 days, reduced starch content 4%, reduced silage dry matter percentage at harvest from 31% to 35%, and resulted in a linear increase in dry matter yield ($P < 0.05$). Another experiment lowering the row spacing from 76 to 38cm (at ~74 000 plants ha^{-1}) did not alter ($P > 0.05$) any agronomic or quality trait except predicted milk yield (tha^{-1}). Narrow row spacings may increase ($P < 0.01$) milk per ha. Lower (2000) CHU hybrids exhibited greater adaptation than those rated >2000 CHU. They yielded more predicted milk per ha with acceptable (>30%) dry matter for ensiling as plant density increased, at any row spacing.

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1.1 Introduction

Animal feed production in Alberta is a significant sector of agricultural production, supporting the requirements of a large livestock industry. In Alberta in 2004, 550 000 ha were used in the production of greenfeed and silage, resulting in 2.20 million tonnes of forage (AAFRD 2005). Additionally, 7.39 million tonnes of tame hay were produced in Alberta that year (Stats Canada 2005). The two main crops grown for silage in Alberta are barley (*Hordeum vulgare* L.) (39%) and oats (*Avena sativa* L.) (45%) (AAFRD 2005). In 2004 silage oats and barley yields averaged 17.8 and 17.0 tonnes per ha, respectively (AAFRD 2005). Maize (*Zea maize* L.) in Alberta is produced on 14 000 ha, mainly in the in the south east portion of the province. Overall average yield of maize in Alberta in 2004 was 41.5 tonnes per ha (AAFRD 2005). This large yield advantage has resulted in a small but steady increase of corn acreage. However this growth has been mainly limited to warmer southern regions of the province. Two factors that have prevented expanded acreage in the past were the lack of early maturing varieties and the lack of weed control options (White 1978). Early maturing hybrids capable of reaching silage maturity in the short season environment of central Alberta have recently been developed (Pioneer Hi-Bred 2002). Advances in herbicide tolerance genes now provide adequate weed control options during early growth, when maize plants are susceptible to weed competition (Johnson 2000). These new developments have increased interest in expanding maize growing areas in the Prairie Provinces, possibly allowing a northward expansion of maize production into central Alberta.

Maize is a cereal crop of tropical origin. Despite the northern climate of central Alberta (Edmonton 53.3° N), the growing season averages 121 days free of frost (AAFRD 1998). The early maturity hybrids now available are rated as 72 days corn relative maturity (CRM), indicating they should reach physiological maturity in Minnesota USA environments in 72 days. Growth rates of maize are highly dependant on temperature and thus do not perform as well in the cooler climate of central Alberta. In the US Corn Belt, where maize production intensity is the highest, temperatures during July average 21.7 to 26.7 °C. In central Alberta, the July average temperature is approximately 16.4°C (Environment Canada 2004). Matching hybrids to these new environments requires testing of varieties and establishment of management practices suited to the region.

Silage maize is generally grown as a full season crop. This period consists of the time from last spring frost until the time of average fall frost. Hybrids are selected for the specific climatic conditions of an environment, allowing maximum utilization of the growing season with the highest possible photosynthetic duration to optimize yield. Troyer and Brown (1976) defined an adapted variety as one that flowers late enough to provide adequate plant size but early enough to complete grain filling in an average season. Maize silage is considered mature when whole plant moisture content is 60-70% and the cob is fully formed before a killing frost (OMAFRA 2002[1]). Thus, a combination of plant size, flowering date and dry-down characteristics must be balanced to produce a successful crop.

Agronomic practices and management can have a large impact on growth and development of maize. Plant development is limited by the resources available to the plant. Crop development is an interaction between all the plants sharing a given environment. The availability of water, light, and nutrients all affect photosynthesis and growth. Determination of how the environment will interact with agronomic practices for the successful production of maize in central Alberta was a desirable objective. Specifically tested in this thesis were plant population densities and the spatial arrangement of maize plants in the field.

In 2002 and 2003, three agronomic experiments were conducted in multi-location trials to determine the effect of certain agronomic practices on growth, development, yield and quality of silage maize produced in the central Alberta environment. Crop yield is dependant on the combined output of the entire population. Plant stands of insufficient number cannot fully utilize the available resources. Plant populations that are excessive must share an inadequate pool of resources. Maize hybrids of varied maturity were tested at four plant populations between 49,000 to 124,000 plants per ha. Data was collected on growth, development, yield and maturity.

Plant size and spatial arrangement of plants in the field determines leaf area index. Leaf area index is an indicator of how much sun light is intercepted by the crop. During the early spring, when plants are small, much of the light falls on bare ground. Canopy closure is achieved when the leaf area is sufficient to achieve complete ground cover, thus intercepting all the available light. Spatial arrangements that optimize the crop's ability to achieve canopy closure increases yield potential. Studies have indicated that a more equidistant spatial arrangement of plants achieved by planting in narrow rows can increase yield (Porter et al., 1997; Cox et al. 1998; Barbieri et al. 2000; Lambert and Lowenberg-Deboer 2001). Thus a study of two row spacing arrangements was undertaken.

The goal of the research was to evaluate new early hybrids to determine potential suitability for production in the central Alberta environment. Experiments were conducted to provide a range of treatments that could be used to determine sound agronomic practices for this new environment. Results may then be employed for the development of recommendations to producers.

The following review of literature covers maize and maize production as forage, production in short season environments, agronomic and environmental factors that affect production and the methods used to assay the quality of the end product.

1.2 Maize (*Zea mays* L.)

1.2.1 Origin and History of maize

Maize (*Zea mays L.*) is a cereal crop grown globally. Maize is a tropical grass and is a member of the *Gramineae* family (tribe *Maydeae*). The center of origin is in the America's, with evidence of cultivation dating back 4700 years in Tehuacan Mexico (Mangelsdorf et al. 1967, MacNeish et al. 1972, Long et al 1989). Samples from Guila Naquitz have also indicated maize was grown in the Mexican highlands 6250 years ago (Piperno 2001). The earliest archeological evidence from this time already showed a high degree of modification from selection by humans. By the time the America's were discovered by Europeans, maize was cultivated in many parts of Central, South and North America.

Maize cultivation for several thousand years in the America's resulted in the development a number of distinct races of maize (Goodman 1976). Races of maize that contributed significantly to current global production originate from 9 main populations that were developed by early civilizations (Goodman, 1976). Northern flints of North America were crossed with Mexican dents to produce the corn-belt dent. Populations of Cuban and Argentine flints, Central American dents, Tropical semi-flints, Costal tropical flints, Tusons, Coroico types, and Andean diversity have also contributed to current varieties. During early voyages maize was brought from the Americas to Europe, where it was further spread around the world.

The ancestry of maize was the subject of much conjecture for a number of years. It was known that maize had a number of relatives within the Maydeae tribe. Maize, teosinte (*Euchlaena mexicana*), and *Tripsicum* sp. are New World Maydeae tribe members. It was unknown if maize originated from wild maize that has since disappeared, or if one of the other relatives was the progenitor of maize. In 1939 George W. Beadle (1939) proposed that teosinte was domesticated to form maize through evidence of chromosome pairing during mitosis in maize x teosinte crosses. Weathermax (1954) proposed that maize, *Tripsicum*, and teosinte all evolved from a common ancestor. Mandelsdorf (1974) proposed that teosinte originated from maize rather than the reverse. To prove that teosinte was the wild progenitor of maize, Beadle (1980) created a population to examine the frequency of parental types in F2 segregates of teosinte x maize crosses, hypothesizing that a small number of major genes were responsible for the differences in phenotype. By examining 50 000 F2 progeny, Beadle (1980) was able to conclude that teosinte was genetically the same as maize and that 5 major genes were involved in the morphological differences. There are thus five key traits separating teosinte from maize: 1) Maize has lateral branches that are short and contain female ears, whereas teosinte has long lateral branches containing male inflorescences (tassels); 2) Each cupule in maize produces two kernels while teosinte produces only one; 3) in teosinte the ear only bears fruit on two sides where as maize has a minimum of four rows of kernels; 4) teosinte has an abscission layer for fruit dispersal while maize ears remain intact at maturity, and; 5) teosinte forms a hardened fruit case with the glumes protecting the seed while maize has visible kernels that are uncovered once the husk is removed.

Genetic analysis of a population created using Beadle's original parents (using molecular markers) added evidence to the theory that maize originated from teosinte, and suggested five major regions responsible for the differences between teosinte and maize (Doebly 1991). This held true with subsequent populations created using different parents (Doebly 1993). At present, the currently accepted theory is that teosinte is the progenitor of maize.

1.2.2 Global and domestic production

In terms of production, maize is the largest crop in the world (Table 1.2.2). In 2004 global production of maize was 705 million Mt followed by wheat (624 million Mt) and rice (608 million Mt) (FAO 2005). Wheat and rice were both planted on greater land area than maize (Table 1.2.2), however average maize yields from 2001-2004 were 59% and 16% greater than wheat and rice, respectively. In 2004 the United States was the largest producer of maize with 298 million Mt, followed by China (132 million Mt) and Brazil (42 million Mt) (FAO 2005). In Canada, 8 million Mt were produced in 2004 (FAO 2005). Maize production in Canada has increased over the last four decades in terms of both absolute tonnage and yield (see Figure 1.2.2.1). Acreage of maize harvested in Canada increased dramatically from 1961 to 1980 and has since fluctuated, with a slight overall increase over the last 25 years (Figure 1.2.2.2).

In juxtaposition with rice and wheat, maize is not used primarily for human consumption (Table 1.2.2.3). The main uses of maize are feed, food and industrial applications. In 2002, the use of maize globally broke down as follows: 64% feed, 18% food, 10% food manufacture, 4% waste, 3% other uses and 1% as seed (FAO 2005). In the developed regions of North America 72% of maize was used for feed, 23% for food manufacture, 3% other uses, 2% food, <0.3% for seed and <0.1% waste. Increasing ethanol production for use as a gasoline additive may alter future allocations of the maize crop in North America. The ethanol production market is expected to surpass the export market in the U.S. by 2008 (Pore 2005). Most maize produced is used domestically; in 2003 only 14% (88 million Mt) of maize production was exported globally (FAO 2005). Exports from the United States accounted for 50% of globally traded maize, followed by 19% from China and 14% from Argentina (FAO 2005). Maize production in Alberta is largely used to produce forage for use in animal feed. The production area of maize in Alberta has tripled from 1995 to 2004; from 4000 ha to 14000 ha in that time period (AAFRD 2004).

1.2.3 Genetics and Breeding of maize

Maize (2n=20) is a diploid plant with separate male and female inflorescences. Pollination occurs by wind, where pollen is carried from the male tassel to the female silk. Maize breeding by humans has occurred over thousands of years through simple selection. By the time of the European discovery of the Americas there were a number of distinct maize races that were widely dispersed throughout North and South America. During the 1800's in the USA soft kernelled southern varieties were grown in combination with early maturing hard kernelled northern flint varieties used to replant areas of poor stand (Wallace and Brown 1956). Cross pollination of these two varieties gave rise to Corn Belt dents (Wallace and Brown 1956). During this time, the showing of maize at fairs became popular, resulting in breeding for uniformity of the ear to develop an ideal type ear. Maize show competitions lead to the spread of specific open pollinated lines. During this period yield increases in maize were mostly stagnant, with nearly no increase in yield in the 70 years leading up to the introduction of hybrids (Troyer 1999). In the late 1800's there was an increased interest in developing inbred lines to be used for producing uniform lines. Early observations of self pollinations compared with out-crossing in the plant kingdom lead Charles Darwin to conclude that inbreeding had negative effects, while cross pollination improved plants (Darwin 1876). In the early 1900's inbred lines that had decreased yield and vigor were used to produce hybrid offspring that recovered vigor, and even outperformed parental lines from which the inbred lines were originally derived (Shull 1908). In addition, these lines exhibited a high degree of uniformity.

Breeders eager to create hybrids found early on that inbred lines experience significant inbreeding depression. Such lines were poor producers of seed and pollen. This resulted in low seed production for single cross hybrids (AxB). D.F. Jones (1922) found a way to improve the output of commercial seed produced by performing a double cross (AxB)x(CxD). In this manner seed production is derived from a hybrid (AxB) rather than an inbred line, allowing higher volumes of seed to be produced. Maize continued to be grown as open pollinated lines until the early 1930's, when the first commercially viable hybrids were developed. In 1935 10% of the maize grown in Iowa was hybrid seed; this increased to 90% by 1939 (Crow 1998). By the early

1950's corn-belt production was entirely double cross hybrids. By improving inbred line vigor, single cross hybrids became commercially viable and began to replace double cross hybrids by the end of the 1950's (Goodman1976).

During 1969 the lack of genetic diversity in maize hybrids was exposed when maize using the T cytoplasmic male sterility system for hybrid production was severely infected by southern corn leaf blight (*Helminthosporium maydis*) (Laughnan et al. 1983). During this period, 85% of acreage possessed this genetic background, resulting in massive crop losses. In the 1970's, nearly 70% of the maize grown in the USA was based on only 6 inbred lines (Sprague 1972). Since this time, breeding efforts have shifted to population improvement to incorporate traits such as disease resistance or agronomic improvement, followed by inbred development from these populations.

Genetic diversity for future breeding population improvements can be derived from collections such as the International Maize and Wheat Improvement Center (CIMMYT) collection of over 250 races of maize, or the nearly 12,000 Latin American collections maintained by the national academy of sciences and the Rockefeller institute (Sprague 1976). CIMMYT maintains a large number of maize samples from which germplasm can be introduced to breeding programs. In 2001 the CIMMYT gene bank maize collection contained 17,000 samples (Pardey 2001).

When early plantings of maize do not result in adequate plant populations due to seedling losses, areas of poor stand are often replanted (Benson, 1990). Such areas are replanted with early maturing varieties that do not utilize the entire growing season (Lauer 1997). It is the development of replants for established maize growing regions (and breeding programs for northern regions) that has allowed for the expansion of maize growing regions to shorter season environments. Once these new environments become established maize markets, earlier maturing replants are developed for these shorter season environments. Maize breeding has also entered into the era of biotechnology with an increasing number of transgenic traits available for improving adaptation of commercial hybrids. An example of this is freezing tolerance in maize conferred by the transgene *Nicotiana* PK1 (Shou 2004).

Early maturing hybrids, capable of silage maturity in central Alberta, will encounter many stresses associated with cool temperatures. An important source of genetic variation for adaptation to cool environments is highland maize from central Mexico. Eagles (1994) reported that highland maize, a group of ancient landraces cultivated above 2000m, was adapted to cool temperatures (12.5°C – 17.5°C). These varieties were superior to tropical and temperate lines in emergence, photosynthesis and grain filling at low temperatures. Eagles (1990) reported that crosses between these Mexican highland races and elite corn-belt dent lines resulted in lines that would be valuable in temperate maize production. Andean races also may contain similar genetic resources, as some of these lines are adapted to high elevations. A relative of maize, *Miscanthus giganteus* , has been observed to function at much lower temperatures than maize and contains the same C4 physiology (Naidu et al. 2003). This could bring a better understanding of how to improve the cool climate performance of maize, or even become a source of genetic variability.

1.2.4 Physiology and Development of maize in temperate climates

Maize is a warm climate, annual C4 cereal crop. Maize is a cumulative short day plant, requiring a day-length of less than 14 hours to switch from vegetative to reproductive growth phases. Breeding of photoperiod insensitive varieties has allowed maize to be grown further north, where short day requirements can not be fulfilled due to the long days of the northern summer (Hunter et al., 1974). The soil temperature required for germination of maize is 10-13°C (Cardwell 1984). This requirement is higher than traditional crops grown in central Alberta. Spring wheat requires only 3°C (Cardwell 1984). Barley and oats, the two most common crops grown for silage, require 5°C and 6°C, respectively (Cardwell 1984). Ritchie and Hanway (1982) reported that soil temperature was a major determining factor in maize development until the emergence of the apical meristem at the 11 leaf (V6) stage. A study of soil temperatures from 1995 to 1998 by Alberta Agriculture in Fort Saskatchewan Alberta reported an average soil temperature of only 6°C May 1, 12°C by May 20 and 18°C by the end of May (AAFRD 1999). During the period from May 1 to May 20 the germination and emergence of maize would be severely limited.

In the early growth period a crop must establish roots and photosynthetic area (leaves) in order to take up energy and resources needed for further growth. Low temperatures during early growth can restrict growth and photosynthetic performance (Miedema, 1982; Kubien, 2004). During early growth, the larger leaf area the crop can establish the more solar energy can be procured. This energy is then used to produce greater tissue for the interception of increasing amounts of solar energy, ultimately resulting in a higher final crop yield. Cold temperatures (<15°C) during the early growth period can limit seedling vigor and growth (Castleberry et al, 1978).

Estimated minimum temperatures required for growth of maize ranges from 10°C (Brown and Bootsma 1993) to 8°C (Ritchie and Nesmith 1991). This minimum temperature however does not translate into optimal growth rates. The degree to which the competitive ability of maize is reduced in Alberta will depend on the degree to which temperature reduces vigor. Jame et al. (1999) reported that the daily leaf appearance rate of maize reached a maximum at 32°C. Leaf appearance at 20°C was only 50% of the maximum, with a further reduction to 25% at 15°C. In contrast, wheat exhibited maximum leaf appearance rate at 20°C, with 50% of the leaf appearance rate at only 6°C (Jame et al 1999). The slow establishment of a crop can result in poor competitive ability against weeds.

Maize is one of the most productive crops in the world (FAO 2005). The high productivity of maize in relation to other major crops is a result of the underlying photosynthetic machinery. Carbon fixation in plants is the result of the capture of energy from the sun by the process of photosynthesis. The carbon captured is used to produce high energy carbohydrates which are in turn used to produce structures or provide energy for life processes (Stryer 1975). During photosynthesis plants capture light in the chloroplast in two different systems. Photo-system I captures light at a wavelength of 700nm and uses the energy from over 200 captured photons to create reduced nicotinamide adenine dinucleotide phosphate (NADPH), an energy storage molecule (Stryer 1975). Photo-system II captures light at 682nm and uses the energy from hundreds of captured photons to photo-produce electrons to be used as a reductant for several metabolic pathways such as fixing carbon or the creation of carbohydrates (Miyake et al 2002).

Maize is a chilling sensitive species (Fryer et al. 1995). Fryer et al. (1995) reported that maize plants growing at 14°C exhibited an immediate increase in CO_2 assimilation rate when moved to 25°C. This increase was believed to be the result of removal of thermodynamic constraints on photosynthesis. Plants grown at 14°C had a lower concentration of functional PSII centers than were present 48H after transfer to 25°C (Fryer et al 1995). This lowers the capacity of the crop to respond immediately to increased temperature. As a result, maize suffering from cold chilling injury would not be able to fully utilize warm periods in the middle of the day under cool spring conditions. Due to these cellular mechanisms and processes, low temperatures not only limit maize growth thermodynamically, but also induce physiological changes and physical damage. This problem would be exacerbated by long day length conditions, resulting in a greater quantity of photon energy that could not be utilized by the PSII system due to cool temperatures.

The central Alberta environment possesses nearly constant potential for chilling injury in maize. Varieties developed for this region must therefore be tolerant of chilling stress. A general evaluation of inbred lines bred for temperate climates from different origins indicated that temperate lines are better adapted to chilling conditions in the field than tropical lines (Verheul et al. 1996). Verheul (1996) also reported that the cause of this difference between varieties was greater photosynthetic efficiency rather than other factors such as leaf morphology or assimilate use.

Traditional crops in central Alberta such as wheat, barley, and oats utilize a C3 photosynthetic system(Cardwell 1984). Maize is a C4 crop. In C3 physiology the initial product created is 3-phosphoglyceric acid (3-Carbon molecule) that is then shuttled to the Calvin cycle (Salisbury and Ross 1991). In C4 physiology, the initial product is oxaloacetic acid (4-Carbon molecule) which is then converted to either malic acid or aspartic acid (Hatch et al. 1971) and transported into the bundle sheath. In the bundle sheath the 4^{th} carbon atom is oxidized to produce NADPH for energy storage and CO_2 is released (Salisbury and Ross 1991). By this mechanism CO_2 becomes concentrated within the bundle sheath. Within the bundle sheath, the Calvin cycle is the same as in C3 plants (Salisbury and Ross 1991). The increased concentration of CO_2 permits the Calvin cycle within the bundle sheath to operate at a much faster rate. Because CO_2 can be captured from low concentrations in the atmosphere and concentrated in the bundle sheath, C4 plants can fix carbon at a higher rate than C3 plants (Salisbury and Ross 1991).

A study of carbon fixation in C3 and C4 plants by Grodzinski et al. (1998) demonstrated that at ambient CO_2 levels C4 plants exhibit a photosynthetic range of 20-30 μmol C m^{-2} s^{-1} while C3 plants exhibit a range of 5-15 μmol C m^{-2} s^{-1} . The rate of photosynthesis was increased in C3 plants by increasing the ambient CO_2 concentrations (Grodzinski et al. 1998). This mechanism has implications in C4 crops' ability to utilize resources compared with C3 crops. In a study of the differences between C3 and C4 crops, Hesketh (1963) reported that the light response of maize (C4) was greater than that of orchard grass (*Dactylis glomerata* L.), a typical C3 grass. Additionally, the light response of maize continued to increase as light intensity increased, whereas the C3 orchard grass showed a rapid leveling off of response. Increased fixation of CO_2 in maize resulted from the C4 CO_2 concentrating mechanism. C4 crops concentrate CO_2 in the bundle sheath, allowing for a supply of CO_2 during periods of high light intensity. In the environment of central Alberta poor adaptation of maize to the cool temperatures may limit photosynthesis. Examination of the photosynthetic enzyme Rubisco in cool climate grown C4 grasses indicated that the activity level was dependant on temperature and corresponded to photosynthetic rate (Kubien et al. 2004). Adaptation of enzymatic pathways to cool temperatures may allow C4 physiological advantages to be more fully utilized in sub-optimal temperatures as is seen in cold tolerant C4 species (Caldwell 1977).

Respiration in plants involves the conversion of stored energy in carbon compounds produced in photosynthesis to useful energy compounds such as ATP (Stryer 1975). This energy is then used to carry out life processes such as creating compounds or structural features of the plant. If respiration in the plant were slowed, so too would growth, as the machinery of the plant requires energy release for growth. Maintenance respiration fulfills the needs of the growing plant; however it is believed that respiration rates can exceed this level, resulting in wasteful respiration (Quin 1981). Respiration rates are dependent on temperature and genotype; thus high or low temperatures can result in differences in respiration rates, depending on the adaptation of a given variety (Taylor et al 1998). Excessive respiration can result in lost dry matter. Quin (1981) reported high overnight temperatures resulted in excessive respiration, which in turn resulted in 15% whole plant dry matter losses for young maize seedlings. Quin (1981) calculated a 200-300kg/ha grain yield loss due to high night temperature respiration. Average minimum night temperatures in Edmonton Alberta for June, July, and August are 7.7, 9.5, and 8.3°C, respectively (Environment Canada 2004). These low night temperatures may limit respiration, potentially increasing yield.

Net assimilation rate (NAR) is a measure of how much carbon dioxide is being fixed into dry matter in the plant relative to the total leaf area. There are two aspects to net assimilation rate: the rate of carbon fixation by photosynthesis, and the rate of CO_2 evolution by respiration. The rate of photosynthesis reaches a maximum around anthesis, when the crop switches from vegetative to reproductive growth (Albrizio and Steduto 2003). The net assimilation rate achieved by maize will depend on the balance between photosynthetic and respiratory rates. The net assimilation rate is dependant on the climatic conditions, agronomic decisions and how these factors are managed in production. Photosynthesis does not occur in isolation, thus environmental parameters ultimately determine outcome. Temperature is a critical factor in the rate of maize plant development (Jame 1999; Miedema, 1982; Kubien, 2004). Nutrient status and plant stress are important factors in determining how well a plant will actually perform. In cool climates enzyme kinetics are limited by temperature (Kingston-Smith et al 1997). The C4 physiology of maize may give distinct advantages in net assimilation rate during long intense daylight periods, but only if capable of operating at high photosynthetic rates. The photosynthetic rate is dependent not only on the intensity of light but on temperature (Foyer et al 2002). Respiration rates will also be affected by the climate. Cool night temperatures will lower respiration rates, affecting the net assimilation rate. During the cool summers of the northern latitude of central Alberta temperature may limit the NAR of maize.

1.3 Forage Maize

1.3.1 Silage production

Ensiling is the process whereby green forage is preserved by acidification (lactic acid production) as a result of anaerobic fermentation, mainly by lactic acid bacteria (Rooke 1991).

There are two main periods in silage preservation: the aerobic phase and the anaerobic phase. The aerobic phase occurs when the crop is first placed for silage in a pit, bag, silo etc. The crop is cut to short lengths by the harvester and transported to the storage location. There the silage is tightly packed to remove airspaces within the silage and sealed to prevent air from entering. Oxygen remaining in the forage is available for aerobic processes. Failure to pack and seal the forage can result in dry matter losses and spoilage. In well packed, sealed silage, the aerobic phase uses the remaining oxygen by respiration of the crop, and microbes in the silage produce carbon dioxide and heat. Excessive respiration can lead to production of excessive heat (OMAFRA 2002[1]). This can lead to poor ensilement with a higher final pH and poor aerobic stability during unloading (Weinberg et al. 2001).

Once oxygen is depleted the aerobic phase ends. The aerobic phase degrades carbohydrates and other nutrients in the forage, so a shorter aerobic phase results in higher dry matter yield and higher quality. Ensilement practices that reduce the availability of oxygen are beneficial. Harvesting the crop at the proper maturity, cutting the forage to optimal cut length (Johnson et al. 2002), packing the silage and rapidly sealing the storage unit to exclude oxygen (Muck 1999) all encourage rapid cessation of the aerobic phase.

The anaerobic phase occurs as rapidly increasing numbers of anaerobic bacteria begin the fermentation process, and aerobic bacteria cease functioning due to lack of oxygen. Heat produced by the aerobic respiration of plant tissue slightly raises the temperature of the silage, favoring growth of lactic acid bacteria (Stoskopf 1981). During this stage lactic acid bacteria produce lactic acid through the utilization of water soluble carbohydrates under anaerobic conditions. Lactic acid lowers the pH of the silage. The presence of water soluble carbohydrates allows lactic acid bacteria to thrive and multiply, increasing the rate of lactic acid production in the silage.

Maize water soluble carbohydrate levels are higher than those of alfalfa (79 g/kg vs 36 g/kg) (McAllister and Hristov 2000). Higher levels of water soluble carbohydrates allow rapid fermentation and greater pH reduction. Reduction of pH also depends on the buffering capacity of the forage. Maize, barley and alfalfa have buffering capacities of 91, 411, and 940 meq/kg respectively (titration from pH 6.6 to 4.0 with 0.1 M HCl) (McAllister and Hristov 2000). A low buffering capacity allows pH to be decreased with less acid produced as buffers resist pH change. Fermentation progresses until the pH drops to a level that inhibits microbial growth, resulting in preservation of the silage. If ensilement favors growth of clostridial bacteria over lactic acid bacteria, butyric acid will be formed; decreasing the quality and intake of the silage (Cushnahan et al. 1995). The key factors in proper ensilement are the water soluble carbohydrate content, the buffering capacity, the moisture content, predominant microorganisms and fermentation speed.

The water soluble carbohydrate concentration in maize is adequate at a large range of maturities, making acidification possible for a wide range of harvest dry matter content. The buffering capacity of maize is low, allowing pH to drop with less buffering, thereby requiring less acid to be produced (Fisher 1987). Maize thus requires less water soluble carbohydrates to be degraded for safe preservation, resulting is less dry matter losses than in most forages.

Moisture content of forage maize is an important issue in central Alberta as variability in season length will result in immature silage maize in some seasons. Lower moisture content favors lactic acid bacteria, whereas moisture contents greater than 70% can favor clostridial type bacteria (OMFRA 2002[1]). High moisture levels can also decrease dry matter intake by animals, decreasing the productivity of the operation (Bal et al. 1997). By rapidly harvesting and limiting oxygen in a crop of proper maturity, dry matter loses during aerobic and anaerobic phases will be limited.

1.3.2 Silage

Maize silage systems have the potential to substantially increase the carrying capacity of a farming operation. This is important in Alberta as feed costs are the greatest expense of livestock production (AAFRD 2005[2]). Additionally, it is important for producers to have adequate well-stored nutritional feed during the winter months. Silage can be harvested under almost any weather condition. This gives it distinct advantages in central Alberta where a short harvest window is often disrupted by periods of wet weather which may prevent other harvesting techniques. Because forage harvest can be accomplished quickly and in a timely manner, the quality of the feed is generally consistent and uniform.

Maize silage is a good quality feed for use in dairy and beef production. Maize has high fiber content with relatively low lignin (Coors and Lauer 2001). The starch contained in the maize grain is a high energy carbohydrate source. The main deficiency of maize silage is that it is low in protein (Sniffen et al. 1992). Feed rations utilizing maize silage can be supplemented with sources of protein to balance the ration (Schwab 1976). Dhiman and Satter (1997) reported that using ratios of 1/3 maize silage to 2/3 alfalfa silage increased milk yields and provided economic benefit to dairy production, when compared with alfalfa alone.

In order to produce high quality maize silage, a maturity level must be reached such that the whole plant moisture content is 58-70%, with an optimum of approximately 65% (Bal et al. 1997). Maize that is more advanced in maturity will make exclusion of oxygen in the preservation stage difficult, resulting in greater respiratory loses and heating (Johnson et al. 2002). Maize that does not reach the maturity level of 70% moisture will result in seepage and nutrient loss (Haigh 1997). Seepage in maize silage is low at dry matter concentrations above 320g/kg, producing 3 liters of effluent per tonne of silage. Seepage increases as dry matter decreases, with 207g/kg dry matter maize producing 65 liters of effluent per tonne (Haigh 1997). This reduces soluble portions of the forage such as soluble sugars and minerals, as well as being a major pollutant. One of the main concerns in central Alberta is maturity of the maize crop at harvest. As the currently available hybrids utilize the full growing season in this region, there is a possibility that harvest maturity will not be reached in all growing seasons. Maize grown in Alberta will invariably fail to achieve silage maturity in some seasons, where heat or season length is limited. In a study of immature low starch maize, Fitzgerald and Murphy (1999) reported the quality and productivity in dairy was nevertheless comparable to high quality grass silage.

1.3.3 Measuring the quality of silage

The main forage quality parameters affect feed intake and the rate and extent of digestion (Wheeler and Corbett 1989). Complex carbohydrates in feed are broken down to produce volatile fatty acids or glucose, which are then absorbed by the animal for energy (Owens et al. 1986). Dietary nitrogen in feed can be available directly from the feed or indirectly through the digestion of ruminant microbes that utilize nitrogen in the forage for life processes (NRC 2001). Nitrogen used by microbes in the rumen is converted into essential amino acids. As such, the forage amino acid balance is less important than the overall quantity of dietary nitrogen (Ipharraguerre et al. 2005). The ratio of carbohydrates and dietary nitrogen must be balanced sufficiently for microbial protein requirements to be met (Kalscheur et al 1999). Excess carbohydrates without sufficient protein limit rumen microbial function, thereby limiting digestion. Excess nitrogen intake leads to the production of urea, which is then excreted (Jonker et al 2002).

Silage contains protein in three general categories: non-protein nitrogen, true protein and bound protein. Non-protein nitrogen is the form that most soluble protein is converted to during fermentation. This form of protein is rapidly converted to ammonia and is utilized by microbes in the rumen, or absorbed. True protein is degraded at a moderate to slow rate in the rumen, allowing some to be absorbed by the intestines. Bound protein is resistant to degradation. It is often bound to lignin complexes that are not broken down in the rumen. The carbohydrate fraction of silage can be classified into three categories: sugars and starch, available cell wall constituents and bound cell wall constituents. Sugars and starches are rapidly degraded in the rumen. Starch digestibility can be less than complete, depending on the genotype and the kernel maturation process. The cell wall consists of cellulose, hemicellulose, lignin and ash. Cell wall digestibility mainly depends on the extent of lignification, consisting of a cross-linking of cellulose fibers (Jung 1986), which limits the ability of rumen microbes to digest lignified portions of the cell wall (Van Soest 1994). The available cell wall is slowly degradable and the bound cell wall is unavailable.

The proportion of lignin in forage determines the potential for cell wall digestion (Van Soest 1994). When combined with starch and sugar measurements these quality characters determine available energy of the feed. Fiber content and digestibility of the feed determines the rate of digestion, with less digestible fiber limiting intake and animal productivity (Oba and Allen 1999). Current ensilement technology produces an ensiled product similar to the quality of the original forage (Charmley 2001). Fresh forage can therefore be analyzed and be a predictor of silage quality after preservation. Generally, major changes in forage quality after ensilement are indicators of problems in the ensilement process itself.

The analysis of silage quality can occur by a number of methods used to determine relative proportions of constituents and their digestibility. The Van Soest method (in Perry et al 1999) uses Neutral Detergent to separate the feed into two fractions: Neutral Detergent soluble and Neutral Detergent insoluble. The solubles are the easily digested fraction of the feed. The insolubles are the neutral detergent fiber (NDF) and are the poorly digested portion, consisting mainly of fiber. The digestibility of the NDF fraction is mainly dependent on the extent of lignification (Van Soest 1994). To determine the extent of lignification, the NDF portion of the feed is treated with an acid solution which solublizes the digestible portions and leaves the lignified fiber. The remaining portion is the Acid Detergent Fiber (ADF) and represents poorly digestible portions of the feed containing cellulose and lignin (Givens et al 2000). This information is then used to evaluate forage feed potential.

Feed energy and protein content are often determined through the use of wet chemistry techniques, making the analysis of large numbers of samples restrictive (Valdes 1987). The use of near infrared spectroscopy (NIRS) can be used for determination of a wide range of quality traits to allow for comparisons to be made between large numbers of samples (Stuth et al. 2003). NIRS uses infrared light reflected off chemical bonds within the sample to determine the constituents of the sample and proportions. Reflected light is compared with predictive equations created by determining the spectral reflectance of thousands of samples, using the NIRS and then determining the constituents by traditional wet chemistry methods. The use of NIRS has shown to be accurate for use in silage quality determination (Baker and Barnes 1990). The traits available from NIRS analysis have increased to include all those needed in feed evaluation, and for comparison of breeding lines for forage use. Ash content, protein, nitrogen, fiber, lignin, lipids, minerals, digestibility and anti-quality components can all be quantified using NIRS (Stuth et al. 2003).

Feed value of silage is the nutritive value of the silage combined with the voluntary intake of the forage (Wheeler and Corbett 1989). Intake levels of silage have been reported to be less than intake levels of unensiled forage by an average of 27% (Mayne and Cushnahan 1995). Recent examination of the data by Charmley (2001) has indicted that intake levels have steadily improved from the 1960's to present, with no significant decrease in intake post ensilement. Thus it is the quality of the original forage that becomes the most important factor determining feed quality, as well as the ability to modify the fermentation process with additives and inoculants.

1.4 Maize Production in Alberta

Adaptation of maize to a new environment requires an understanding of the given environment and how the crop will utilize that environment to meet production goals. In Alberta the goals of production depend on the user. Dairy producers prefer a stable and consistent ration for feeding in highly productive dairy operations. Beef cattle producers tolerate higher risk to produce greater tonnage for feedlot operations (Tom Vanmoorsel personal communication). The maize plant can be used to achieve different objectives in different ways. To determine the outcome, the crop's response to the environment must be measured and studied. By determining the relationship between hybrid characteristics and desired outcomes one can then develop lines and production techniques that are adapted to produce a desired outcome in the particular environment. An understanding of the environment, the crop and the outcome goals determines how adaptability will be achieved.

Tillage practices such as conventional till or in-row residue management, which generate warmer soil temperatures, allow for greater rates of plant development in cooler climates (Fortin 1993). Plants growing vigorously can compete with weeds, resist disease, and tolerate insect feeding and other stresses better than plants with lower vigor (Cox et al.1990). Practices that minimize stress on the maize crop, thereby promoting vigorous growth, will be essential in stress climates such as Alberta. Agronomic decisions such as plant density, sowing date and management practices will affect the level of stress experienced by maize.

1.4.1 Alberta environmental conditions

The Canadian prairie environment has a short growing season and soil moisture conditions limiting crop yield potential (McGinn and Shepard 2003). The central Alberta (AB) environment poses a number of challenges to maize production. The frost free period ranges from a low of 109 days to a high of 132 days (AAFRD 1998). Similar short season length in Canada's Maritime Provinces hampers maize production, making the season length limiting in most years (White 1976). Temperature is the most important climatic variable affecting adaptation (Major and Hamilton 1978). The Central Alberta climate is cooler than major maize growing regions, with average accumulated corn heat units of 2000 to 2200 (AAFRD 2003). For marginal areas of maize production such as Central Alberta, temperatures are likely too cool for optimal growth for much of the growing season (Major and Hamilton 1978). In Southern Alberta greater CHU accumulations (2200 CHU to >2400 CHU) (AAFRD 2003) allow for the production of grain maize while areas of lower heat unit accumulation are only suitable for silage maize production (Major and Hamilton 1978). Soil moisture is another important factor in agricultural production in the Canadian Prairies' (McGinn and Shepard 2003). In Manitoba, Hamilton et al (1976) found moisture deficit to be the most limiting environmental factor to maize yield. Alberta has a slightly higher mean daily soil moisture in the top 120cm of soil than Manitoba and Saskatchewan at 82mm, 76mm, and 47mm respectively (McGinn and Shepard 2003). Moisture availability affects feasibility of corn in relation to other crops by reducing yield (Major and Hamilton 1978).

1.4.2 Measuring environmental suitability for maize

Maize is generally grown as a full season crop. As such, there have been systems developed for classification of hybrids to allow producers to select appropriate varieties for specific environments. The growing degree unit system, the Minnesota relative maturity, the modified relative maturity and the maize heat unit system (Ontario heat unit) are three commonly used systems. The GDU system uses an average of the daily maximum and minimum temperatures and subtracts 10°C, the minimum temperature for growth (Troyer 2001). The minimum and maximum temperatures used in this formula are 10°C and 30°C respectively. By determining the average number of growing degree days an environment can be classified. Hybrids are assigned to a GDU rating by measuring how many growing degree days a hybrid requires to mature and by comparing to known check hybrids.

The Minnesota and crop relative maturity (CRM) ratings were originally based directly on the number of days from planting to physiological maturity at a specific location (Troyer 2001). The CRM rating system may not work very well in Alberta because ratings are presently given for regions with much different climates. Ontario corn heat unit maturity ratings provide a more accurate measure of environmental constraints on maize production in the cooler climate of Canadian growing regions (Major et al. 1983). Ontario corn heat units (CHU) use separate calculations for day and night, with a 10°C minimum day temperature and 4.4°C minimum night temperature (OMAFRA 2002[2]). CHU are calculated using the average of the day and night values calculated by the following formulas: Day = $Y_{max} = 3.33(T_{max} - 10)-0.084(T_{max} - 10)^2$; Night = $Y_{min} = (9/5)(T_{min}-4.4C)$ (OMFRA 2002[2]). Pioneer Hi-Bred sales literature recommends an adjustment of -100 CHU for maturity ratings in western Canada to better fit hybrids to this environment (Pioneer Hi-Bred 2002).

1.5 Production of Maize

Photosynthetic efficiency is affected by plants response to stress which may lower rates of photosynthesis (Nissanka et al. 1997; Dwyer and Tollenaar 1989). Improvements in photosynthetic response to stress from cool temperatures, high populations (Dwyer and Tollenaar 1989) and drought (Nissanka et al.1997) have been accomplished through plant breeding in northern growing regions. Yield improvement has resulted from increased stress tolerance in newer hybrids compared to historical ones (Tollenaar and Wu 1999). Progressive breeding has decreased ear bareness and lowered lodging at high densities, allowing increased population stands (Sangoi et al 2002). Efficiency of conversion has also been improved by increasing light interception by photosynthetic active leaf area during the growing season. Adaptations in modern hybrids have resulted in greater light interception and greater tolerance to stresses, ultimately leading to higher yield (Sangoi et al. 2002; Tollenaar and Wu 1999).

Increasing the amount of light intercepted has been accomplished in 3 main areas: 1) decreasing the time it takes the crop to achieve critical leaf area; 2) increasing the leaf area index (LAI) of the crop; and, 3) increasing leaf area duration of the crop. Leaf area index, (LAI) is a measure of the leaf area available for intercepting sunlight as a ratio of the area the plants occupy. Canopy light interception and crop photosynthesis are related to LAI up to the critical LAI, at which point 95% of incident light is intercepted (Pearce et al.1965). Early in the season the leaf area is low, as small seedlings capture small amounts of light while large amounts fall on the bare soil surrounding them. Populations below optimal levels delay canopy closure (critical LAI) decreasing solar radiation interception (Westgate et al. 1997). In a multivariate analysis of maize yields at Purdue, LAI alone accumulated over the growing season accounted for 65% of the variability in yield (Daughtry et al 1983).

Maize growth during early seedling and the vegetative growth period is initially determined by the energy reserves of the seed and then by the capture of light energy from leaves. Maddonni et al. (2001) observed no changes to development of individual plant LAI until the V6 stage in populations between 3 and 12 plants m^{-2}. Thus higher population densities would have four times the leaf area index by the V6 stage and would achieve critical LAI sooner.

Improved lines from breeding and improved cultural practices have improved leaf area index over time (Dwyer and Tollenar, 1989). Plant density increases and even spatial arrangements of the population may improve light interception by altering the LAI (photosynthetic area). Decreases in plant stature, and alterations in plant architecture, have improved light interception and improved productivity (Sangoi et al 2002). Modern hybrids exhibit heterosis for leaf size, resulting in increased LAI (Tollenaar et al. 2004). Lengthened leaf area duration through decreased senescence can also allow better capture of sunlight in later stages of the season (Tollenaar and Wu 1999).

1.5.1 Plant population and crop canopy architecture

Increased plant population has contributed to maize yield improvement over the modern history of hybrid maize production (Cardwell 1982). Hybrids of the modern era exhibited improved tolerance to high population densities compared to those of previous eras (Sangoi et al

2002; Duvick and Cassman 1999). Management of maize historically required inter-row cultivation and rows were therefore spaced at 100cm to allow passage of a horse between rows during cultivation. This limited density to between 14,000 and 20,000 plants ha^{-1} (Stoskopf 1981). Modern equipment and pesticides have replaced horses, allowing more flexible management of maize population densities. Current recommendations for grain production in the central Corn Belt are 54,000 to 69,000 plants ha^{-1} (Norwood 2001).

In some environments increasing plant population density has been shown to increase grain yields up to an optimum density, followed by yield reductions as the optimum is exceeded (Tetio-Kagho and Gardner 1988; Prior and Russell 1975). A summary of research results from US and Canadian studies indicated that yields leveled off at supra-optimal densities rather than decreasing at sites yielding above 7500kg ha^{-1} (Paszkiewicz and Buzden 2001). Studies of forage yields in maize also show dry matter yields leveling off at populations above optimal (Cusicanqui and Lauer 1999), with higher optimal populations noted in favorable environments (Larsen and Clegg 1999). Plant densities for maximum forage yield have been reported to be higher than for grain (Pinter et al 1994; Olsen and Sander 1988). Cox (1997) reported optimum dry matter yields occurred at populations 7.5% higher on average for forage production than grain production. Grain production population density is lower than silage density because grain yield is more sensitive to higher populations than dry matter yield (Pinter et al. 1990).

Increasing plant density will increase leaf area index and dry matter production until the point when competition for resources within the crop limits growth (Maddonni and Otegui 2004). Increasing plant populations increase environmental stress on individual plants as resource availability becomes limiting. Multiple stresses may interact, resulting in increased susceptibility to other sources of stress (Vyn and Hooker 2002). Optimal plant density will depend on the environment in which a crop is grown (Blumenthal et al 2003; Thominson and Jordan 1995). The optimum population for grain and forage production also depends on hybrid genotype. Hybrids can be density sensitive with optimal yields at lower populations, or density tolerant with higher optimum densities (Pinter et al 1994). High population tolerant hybrids exhibit a significant advantage in leaf area index as compared to sensitive hybrids at high density (Pinter et al. 1994). In a study of Brazilian maize hybrids from different eras, the 1990's hybrid C929 maximized grain yield at 85000 plants/ha while the 1980's hybrid A303 and the 1970's hybrid A12 reached an optimum at 79000 and 71000 plants/ha respectively (Sangoi et al 2002).

Maize growth is restricted in short-season areas by cool early season temperatures, low accumulation of corn heat units, and early fall frosts (White 1978). As such, maturity at harvest is an important consideration in central Alberta maize production. To be considered adapted, maize must reach 70% whole plant moisture before a killing frost (Major and Hamilton 1978). Daynard and Hunter (1975) reported maximum dry matter yield occurred at 66-70% whole plant moisture. Increasing plant densities can delay silking and maturity (White 1976). This may be dependant on hybrid as Phipps (1979) reported no difference in maturity in response to density treatments for a density tolerance hybrid. Modarres et al. (1998) reported that inbreds carrying reduced stature traits (RS) did not exhibit silking delay at high population densities, while normal stature hybrids flowered later at high densities. Increasing plant density can alter the silage characteristics of the resultant forage (Widdicombe and Thelen 2002; Pinter et al 1994). There has been no work on optimal plant populations for corn silage production in Alberta.

1.5.2 Row Spacing and crop canopy architecture

Optimal row widths in maize production have become increasingly narrow as plant densities have increased (Duvic and Cassman 1999). Maize grown at a given population intercepts a greater proportion of the incident radiation, increases LAI, and increases the efficiency of light interception when grown at narrow row spacing (Bullock et al 1988). In low density populations, narrow row spacing allows for more equidistant planting arrangement and improved light attenuation (Maddonni et al 2001). More equidistant planting in narrow row spacing can decrease stress from interplant competition for nutrients (Barbieri, 2000).

Hybrid genotype can affect the response to narrow row production with strong hybrid x row spacing interactions reported (Farnham 2001). Maddonni et al. (2001) reported that some hybrids were unable to adjust leaf distribution to adjust for interplant shading competition for light while others showed a great deal of flexibility. Studies in northern US have shown less hybrid x row spacing, interactions with narrow row spacing having distinct yield advantages (Porter et al 1997; Cox et al 1998). It may be that hybrids adapted to northern environments are also innately adapted to narrow row spacing. Hybrids adapted to temperate environments are short in stature, have lower leaf area and are source limited (Hunter 1980). Hunter (1977) reported that short season hybrids achieve low LAI resulting in a maximum of only 75% of sunlight intercepted. Inability of the crop to reach critical leaf area index (95% light interception) was the main criterion listed by Maddonni et al. (2001) for improved light interception from narrow row spacing.

Ideal row width is dependant on the environment where a given hybrid is grown. In a summary of research on narrow row spacing Gray (1999) reported a 6.2% advantage for narrow row spacing in the northern US. This diminished as trials moved further south to a 4.1% disadvantage in the southern US (Grey 1999, In: Farnham 2001). A similar result was noted in a research summary by Paskiewicz (1997) who suggested an 8% yield advantage in narrow row production for locations above 44° N compared with only a 4% overall advantage. Narrow row spacing under adequate fertility have been reported to result in grain yield increases of <10% (Bullock et al 1988, Porter et al 1997). Lambert and Lowenberg-DeBoer (2001) reported that yield increases were inconsistent with increases in stalk breakage and management costs. Narrow row spacing resulted in greater yield response in low fertility conditions than under optimal fertility (Barberi et al 2000).

1.5.3 Sowing Date Studies

Maize is generally planted as a full season crop utilizing the entire growing season to maximize production. As such, general recommendations for maize have been to sow as early as possible to maximize available season length (AAFRD 2005 [3]). Delaying planting decreases the season length requiring producers' to plant a shorter season hybrid or increase the risk of fall frost before maturity. Early planting has associated risks; such as frost, poor emergence and slow early plant growth (Fairly 1983). In season-limited production areas fall frost often prevents the crop from reaching physiological maturity (White 1978). For silage production in extreme short season areas, failure to reach adequate maturity can result in inadequate dry matter for ensilement. A frost that occurs before silage maturity can result in a shorter grain filling period. A decrease in grain filling results in decreased silage quality (Coors et al 1997). In the Corn Belt optimum planting dates are between April 20 and May 10 (Benson 1990). As production moves northward, optimum plant dates become later as the risk of spring frost continues to later dates and available heat for germination diminishes (Lauer et al 1999). In a study of planting dates from 1991 to 1994 in Wisconsin Laurer et al. (1999) reported the optimum planting at southern Wisconsin locations to be May 1 to May 7 with 95% of optimum between May 9 and 18th.

1.6 Conclusion

Maize represents one potential option for increasing forage productivity for the livestock industry in Alberta. Data from the southern regions of Alberta indicate that maize is capable of achieving large yield advantages over traditionally grown Alberta forages (AAFRD 2005[1]). While maize is capable of greater rates of growth than traditional Alberta crops, such growth rates may not occur due to climatic constraints. Environmental factors such as long days and cool nights may allow maize to perform better than expected from available heat projections alone. Agronomic research to optimize output of current hybrids in central Alberta is needed.

1.7 Statement of Purpose

1.7.1 Purpose of research

New maize hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. Demand for these hybrids has increased for use as forage by dairy and beef cattle producers. Agronomic evaluation of early maize varieties is necessary to determine yield potential, and optimum management practices for Alberta. The central Alberta environment poses a number of challenges to maize production. The season length is short, ranging from a frost-free period of 109 days at the Edmonton international airport to 132 days at the Namao airport (AAFRD 1998). The climate is cooler than current maize growing regions, with average accumulated crop heat units of 2000-2200 (AAFRD 2003). This range is currently the lower limit of maturity ratings for available hybrids. Cool conditions reduce the rate of crop development, making the season length limiting in most years.

Information on growth and development of the crop, and subsequent yield, maturity and quality are unavailable in central Alberta. Information on the development of the crop under different populations, crop architectures and sowing dates is essential for determining the suitability of present hybrids and for the development of future hybrids.

1.7.2 Thesis Objectives

The objectives of this thesis research are:

1) To evaluate the effect of hybrids of varied maturity ratings, planted at a range of plant densities, on yield, maturity and quality in central Alberta.
2) To determine the effect of row spacing on yield, maturity and quality.
3) To determine if silage maize is a potential cropping option for central Alberta

1.7.3 Thesis Null Hypothesis

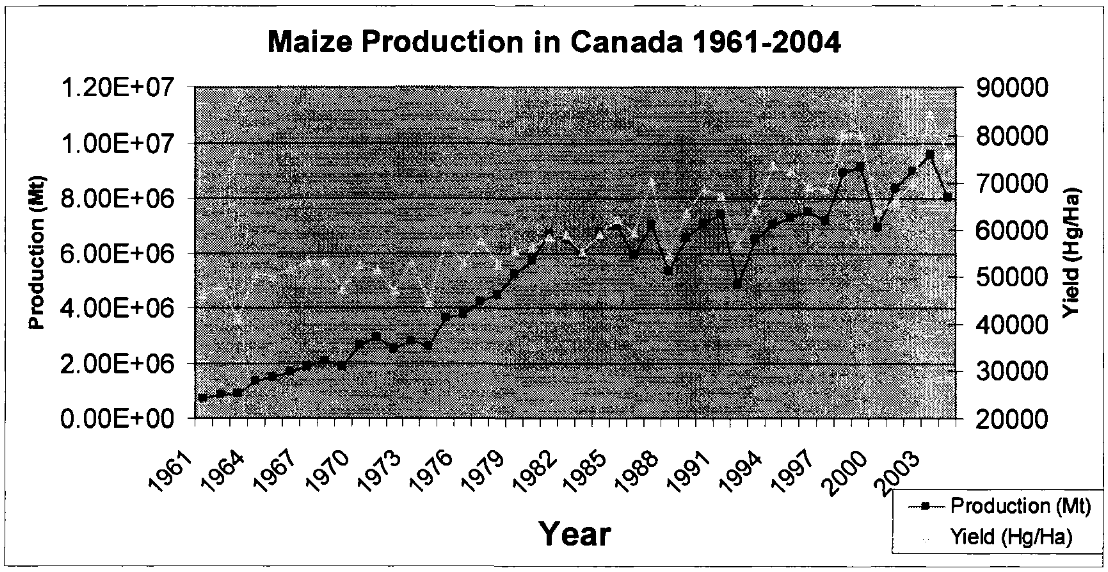
The null hypotheses tested through this thesis research are:

1) Hybrids of varied maturity ratings grown at varied plant densities will not differ for yield, maturity or quality.

2) Altered spatial planting arrangements do not alter maize yield, maturity, or quality.

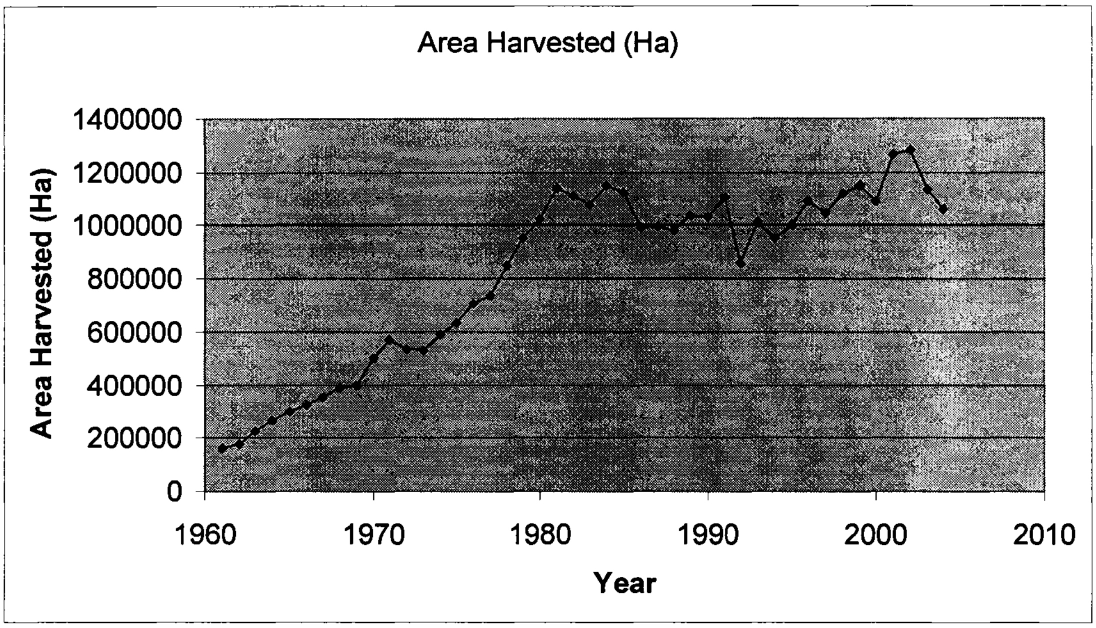
1.8 Figures

Figure 1.1 Maize production and yield in Canada 1961 – 2004



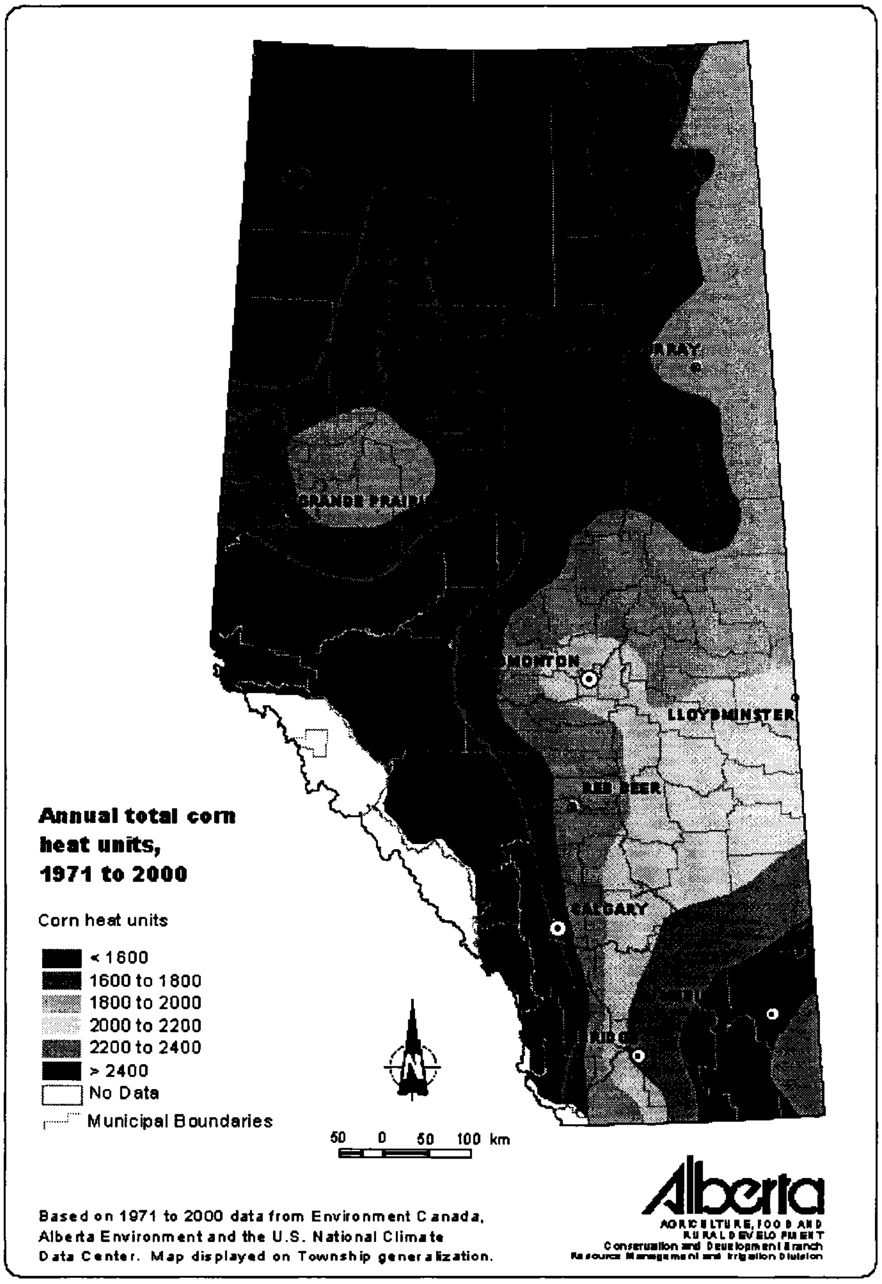
Source: FAO 2005

Figure 1.2 Maize production acreage in Canada 1961 – 2004



Source: FAO 2005

Figure 1.3 Alberta Climate normals: CHU availability



Taken with permission from: AAFRD (2003) Annual total corn heat units, 1971 – 2003. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6442/$FILE/onl_s_9_twp_annual_normals_19712000.gif

1.9 Tables

Table 1.1 Global Production, yield and land use for Maize, Wheat, Rice and Soybean.

	1966-1970			1971-1975			1976-1980			1981-1985		
		% increase	% Wheat		% increase	% Wheat		% increase	% Wheat		% increase	% Wheat
Area Harvested (Ha)												
Maize	1.1E+08	5	51	1.2E+08	6	54	1.2E+08	5	54	1.3E+08	1	54
Rice, Paddy	1.3E+08	7	60	1.4E+08	5	62	1.4E+08	5	62	1.4E+08	0	61
Wheat	2.2E+08	3	100	2.2E+08	1	100	2.3E+08	6	100	2.3E+08	1	100
Soybeans	2.8E+07	15	13	3.5E+07	24	16	4.5E+07	29	20	5.2E+07	14	22
Production (Mt)												
Maize	2.6E+08	22	85	3.2E+08	21	90	3.9E+08	22	92	4.4E+08	13	90
Rice, Paddy	2.9E+08	19	93	3.3E+08	15	93	3.7E+08	14	89	4.4E+08	18	91
Wheat	3.1E+08	25	100	3.5E+08	15	100	4.2E+08	19	100	4.9E+08	15	100
Soybeans	4E+07	41	13	5.4E+07	34	15	7.5E+07	40	18	9E+07	20	19
Yield (Hg/Ha)												
Maize	23407	16	165	26873	15	166	31003	15	170	34593	12	166
Rice, Paddy	22212	12	156	24127	9	149	26191	9	144	30800	18	148
Wheat	14224	21	100	16197	14	100	18206	12	100	20794	14	100
Soybeans	14177	23	100	15317	8	95	16551	8	91	17505	6	84

	1986-1990			1991-1995			1996-2000			2001-2004		
		% increase	% Wheat			% Wheat		% increase	% Wheat		% increase	% Wheat
Area Harvested (Ha)												
Maize	1.3E+08	4	58	1.4E+08	3	62	1.4E+08	3	63	1.4E+08	1	63
Rice, Paddy	1.5E+08	1	65	1.5E+08	1	67	1.5E+08	4	69	1.5E+08	-1	69
Wheat	2.2E+08	-4	100	2.2E+08	-2	100	2.2E+08	0	100	2.1E+08	-3	100
Soybeans	5.5E+07	7	24	5.9E+07	7	27	6.9E+07	17	31	8.3E+07	20	31
Production (Mt)												
Maize	4.6E+08	5	86	5.2E+08	13	94	6E+08	15	101	6.4E+08	7	101
Rice, Paddy	4.9E+08	11	92	5.3E+08	9	97	5.9E+08	10	99	5.9E+08	1	99
Wheat	5.3E+08	10	100	5.5E+08	3	100	5.9E+08	8	100	5.9E+08	-1	100
Soybeans	1E+08	11	19	1.2E+08	18	22	1.5E+08	26	25	1.9E+08	25	25
Yield (Hg/Ha)												
Maize	35029	1	148	38211	9	153	42865	12	159	45225	6	159
Rice, Paddy	33623	9	142	36147	8	145	38426	6	143	39086	2	143
Wheat	23674	14	100	24956	5	100	26916	8	100	27446	2	100
Soybeans	18310	5	77	20135	10	81	21804	8	81	22788	5	81

Source: FAO 2005

Table 1.2 Food use of Maize, Wheat, Rice and Soybeans 1961-2004

		1961-1965			1966-1970			1971-1975		
			% Food	% of Wheat		% Food	% of Wheat		% Food	% of Wheat
Maize	Production (Mt)	2.1E+08			2.6E+08			3.2E+08		
	Food (Mt)	4.8E+07	22	27	5.5E+07	21	28	6.2E+07	19	27
Rice, Paddy	Production (Mt)	2.4E+08			2.9E+08			3.3E+08		
	Food (Mt)	2.1E+08	88	120	2.5E+08	86	123	2.9E+08	88	128
Wheat	Production (Mt)	2.5E+08			3.1E+08			3.5E+08		
	Food (Mt)	1.8E+08	72	100	2.0E+08	65	100	2.3E+08	64	100
Soybeans	Production (Mt)	2.9E+07			4.0E+07			5.4E+07		
	Food (Mt)	4.7E+06	16	3	5.9E+06	15	3	6.3E+06	12	3

		1976-1980			1981-1985			1986-1990		
			% Food	% of Wheat		% Food	% of Wheat		% Food	% of Wheat
Maize	Production (Mt)	3.9E+08			4.4E+08			4.6E+08		
	Food (Mt)	7.3E+07	19	28	8.3E+07	19	26	9.6E+07	21	27
Rice, Paddy	Production (Mt)	3.7E+08			4.4E+08			4.9E+08		
	Food (Mt)	3.3E+08	88	125	3.9E+08	87	123	4.3E+08	88	121
Wheat	Production (Mt)	4.2E+08			4.9E+08			5.3E+08		
	Food (Mt)	2.6E+08	63	100	3.1E+08	65	100	3.6E+08	67	100
Soybeans	Production (Mt)	7.5E+07			9.0E+07			1.0E+08		
	Food (Mt)	6.5E+06	9	2	7.2E+06	8	2	8.5E+06	8	2

		1991-1995			1996-2000		
			% Food	% of Wheat		% Food	% of Wheat
Maize	Production (Mt)	5.2E+08			6.0E+08		
	Food (Mt)	1.0E+08	20	26	1.1E+08	18	26
Rice, Paddy	Production (Mt)	5.3E+08			5.9E+08		
	Food (Mt)	4.7E+08	89	122	5.1E+08	86	123
Wheat	Production (Mt)	5.5E+08			5.9E+08		
	Food (Mt)	3.9E+08	71	100	4.1E+08	69	100
Soybeans	Production (Mt)	1.2E+08			1.5E+08		
	Food (Mt)	1.0E+07	9	3	1.1E+07	7	3

Source: FAO 2005

Table 1.3 Maize relative maturity rating equivalents

Dekalb (US) Relative Maturity (days)	Minnesota Relative Maturity (days)	U.S. Growing Degree Days (GDU)	Canadian Heat Units (OCHU)
75	70	1650	2100
78	75	1750	2300
82	80	1850	2500
86	85	1950	2600
89	90	2050	2700
93	95	2150	2800
96	100	2250	2900
100	105	2350	3200
104	110	2450	3400
108	115	2550	3500
111	120	2650	3700
114	125	2750	3900
118	130	2850	4100
121	135	2950	4300
125	140	3050	4500

Adapted from: Troyer, Forrest. Hallauer, A. Specialty Corns 2nd Ed. 2001 CRC press New York

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Chapter 2

The effect of hybrid and population density on yield and quality of silage maize in central Alberta

Note: This chapter will be submitted to the Journal of Agronomy and Crop Science for potential publication

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Abstract

New maize (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. To maximize productivity and evaluate potential of this new cropping option, agronomic evaluation of new hybrids is needed in this environment. Field experiments were conducted in central Alberta at seven locations between 2002 and 2003. Silage yield, maturity and quality response was evaluated for four short-season Pioneer hybrids varying in maturity from 2000 to 2250 Corn Heat Units. Increasing plant density from ~50 000 to ~124 000 plants/ha^{-1} delayed silking by 5 days. Silage dry matter percentage at harvest ranged from 35% to 31% DM from low to high density, respectively. Yield increased linearly ($P < 0.05$) with increased plant density. Lower (2000) corn heat unit hybrids exhibited a greater adaptation to the region. They yielded more dry matter with acceptable dry matter (>30%) for ensiling as plant density increased. Higher corn heat unit varieties displayed less adaptation to central Alberta, exhibiting decreased yield at higher plant densities with less than optimal dry matter percentage (< 30%) and associated quality characteristics for ensiling.

2.1 Introduction

Animal feed production in Alberta is a significant sector of agricultural production, supporting the requirements of a large livestock industry. In Alberta in 2004, 550 000 ha were used in the production of greenfeed and silage, resulting in 2.20 million tonnes of forage (AAFRD 2005[1]). Additionally, 7.39 million tonnes of tame hay were produced in Alberta that year (Stats Canada 2005). The two main crops grown for silage in Alberta are barley (*Hordeum vulgare* L.) (39%) and oats (*Avena sativa* L.) (45%) (AAFRD 2005[1]). In 2004 silage oats and barley yields averaged 17.8 and 17.0 tonnes per ha, respectively (AAFRD 2005[1]). Maize (*Zea maize* L.) in Alberta is produced on 14000 ha, mainly in the south east portion of the province. Overall average yield of maize in Alberta in 2004 was 41.5 tonnes per ha (AAFRD 2005[1]). Two factors that have prevented expanded silage maize acreage in the past were the lack of early maturing hybrids and the lack of weed control options (White 1978). Early maturing hybrids capable of reaching silage maturity in the short season environment of central Alberta have recently been developed (Pioneer Hi-Bred 2002). Advances in herbicide tolerance genes now provide adequate weed control options during early growth, when maize plants are susceptible to weed competition (Johnson 2000).

Silage maize is generally grown as a full season crop. This period consists of the time from last spring frost until the time of average fall frost. Hybrids are selected for the specific climatic conditions of an environment, allowing maximum utilization of the growing season with the highest possible photosynthetic duration to optimize yield. Maize silage is considered mature when whole plant moisture content is 60-70% and the cob is fully formed before a killing frost (OMAFRA 2002[1]). The soil temperature required for germination of maize is 10-13°C (Cardwell 1984). This requirement is higher than traditional crops grown in central Alberta. Spring wheat requires only 3°C (Cardwell 1984). Barley and oats, the two most common crops grown for silage, require 5°C and 6°C, respectively (Cardwell 1984). Ritchie and Hanway (1982) reported that soil temperature was a major determining factor in maize development until the emergence of the apical meristem at the 11 leaf (V6) stage. A study of soil temperatures from 1995 to 1998 by

Alberta Agriculture in Fort Saskatchewan Alberta reported an average soil temperature of only 6°C May 1, 12°C by May 20 and 18°C by the end of May (AAFRD 1999).

Estimated minimum temperatures required for growth of maize ranges from 10°C (Brown and Bootsma 1993) to 8°C (Ritchie and Nesmith 1991). This minimum temperature however does not translate into optimal growth rates. The degree to which the competitive ability of maize is reduced in Alberta will depend on the degree to which temperature reduces vigor. Jame et al. (1999) reported that the daily leaf appearance rate of maize reached a maximum at 32°C. Leaf appearance at 20°C was only 50% of the maximum, with a further reduction to 25% at 15°C. In contrast, wheat exhibited maximum leaf appearance rate at 20°C, with 50% of the leaf appearance rate at only 6°C (Jame et al 1999). The slow establishment of a crop can result in poor competitive ability against weeds.

Tillage practices such as conventional till or in-row residue management, which generate warmer soil temperatures, allow for greater rates of plant development in cooler climates (Fortin 1993). Plants growing vigorously can compete with weeds, resist disease, and tolerate insect feeding and other stresses better than plants with lower vigor (Cox et al.1990). Practices that minimize stress on the maize crop, thereby promoting vigorous growth, will be essential in stress climates such as Alberta. Agronomic decisions such as plant density, sowing date and management practices will affect the level of stress experienced by maize.

The Canadian prairie environment has a short growing season and soil moisture conditions limiting crop yield potential (McGinn and Shepard 2003). The central Alberta (AB) environment poses a number of challenges to maize production. The frost free period ranges from a low of 109 days to a high of 132 days (AAFRD 1998). Similar short season length in Canada's Maritime Provinces hampers maize production, making the season length limiting in most years (White 1976). Temperature is the most important climatic variable affecting adaptation (Major and Hamilton 1978). The Central Alberta climate is cooler than major maize growing regions, with average accumulated corn heat units of 2000 to 2200 (AAFRD 2003). For marginal areas of maize production such as Central Alberta, temperatures are likely too cool for optimal growth for much of the growing system (Major and Hamilton 1978). In Southern Alberta greater CHU accumulations (2200 CHU to >2400 CHU) (AAFRD 2003) allow for the production of grain maize while areas of lower heat unit accumulation are only suitable for silage maize production (Major and Hamilton 1978). Soil moisture is another important factor in agricultural production in the Canadian Prairies' (McGinn and Shepard 2003). In Manitoba, Hamilton et al (1976) found moisture deficit to be the most limiting environmental factor to maize yield. Alberta has a slightly higher mean daily soil moisture, in the top 120cm of soil, than Manitoba and Saskatchewan at 82mm, 76mm, and 47mm respectively (McGinn and Shepard 2003). Moisture availability affects feasibility of corn in relation to other crops by reducing yield (Major and Hamilton 1978).

Photosynthetic efficiency is affected by plants' response to stress which may lower rates of photosynthesis (Nissanka et al. 1997; Dwyer and Tollenaar 1989). Improvements in photosynthetic response to stress from cool temperatures, high populations (Dwyer and Tollenaar 1989) and drought (Nissanka et al.1997) have been accomplished through plant breeding in northern growing regions. Yield improvement has resulted from increased stress tolerance in newer hybrids compared to historical ones (Tollenaar and Wu 1999). Progressive breeding has decreased ear bareness and lowered lodging at high densities, allowing increased population stands (Sangoi et al 2002). Efficiency of conversion has also been improved by increasing light interception by photosynthetic active leaf area during the growing season. Adaptations in modern hybrids have resulted in greater light interception and greater tolerance to stresses, ultimately leading to higher yield (Sangoi et al. 2002; Tollenaar and Wu 1999).

Early in the season the leaf area is low, as small seedlings capture small amounts of light while large amounts fall on the bare soil surrounding them. Populations below optimal levels delay canopy closure (critical LAI) decreasing solar radiation interception (Westgate 1997). In a multivariate analysis of maize yields at Purdue, LAI alone, accumulated over the growing season, accounted for 65% of the variability in yield (Daughtry et al 1983).

Improved lines from breeding and improved cultural practices have improved leaf area index over time (Dwyer and Tollenar, 1989). Plant density increases and even spatial arrangements of the population may improve light interception by altering the LAI (photosynthetic area).

Decreases in plant stature, and alterations in plant architecture, have improved light interception and improved productivity (Sangoi et al 2002). Increased plant population has contributed to maize yield improvement over the modern history of hybrid maize production (Cardwell 1982). Hybrids of the modern era exhibited improved tolerance to high population densities compared to those of previous eras (Sangoi et al 2002; Duvick and Cassman 1999).

In some environments increasing plant population density has been shown to increase grain yields up to an optimum density, followed by yield reductions as the optimum is exceeded (Tetio-Kagho and Gardner 1988; Prior and Russell 1975). A summary of research results from US and Canadian studies indicated that yields leveled off at supra-optimal densities, rather than decreasing, at sites yielding above 7500kg ha^{-1} (Paszkiewicz and Buzden 2001). Studies of forage yields in maize also show dry matter yields leveling off at populations above optimal (Cusicanqui and Lauer 1999), with higher optimal populations noted in favorable environments (Larsen and Clegg 1999). Plant densities for maximum forage yield have been reported to be higher than for grain (Pinter et al 1994; Olsen and Sander 1988). Cox (1997) reported optimum dry matter yields occurred at populations 7.5% higher on average for forage production than grain production. Grain production population density is lower than silage density because grain yield is more sensitive to higher populations than dry matter yield (Pinter et al. 1990).

Optimal plant density will depend on the environment in which a crop is grown (Blumenthal et al 2003; Thominson and Jordan 1995). The optimum population for grain and forage production also depends on hybrid genotype. Hybrids can be density sensitive with optimal yields at lower populations, or density tolerant with higher optimum densities (Pinter et al 1994). High population tolerant hybrids exhibit a significant advantage in leaf area index as compared to sensitive hybrids at high density (Pinter et al. 1994). Increasing plant density can alter the silage characteristics of the resultant forage (Widdicombe and Thelen 2002; Pinter et al 1994). There has been no work on optimal plant populations for silage production in Alberta.

The objectives of this experiment were: 1) to evaluate the effect of different hybrids of varied maturity ratings planted at a range of plant densities on yield, maturity, and quality across central

AB environments. 2) To determine the relationship between crop developmental parameters and final outcome of yield, maturity, and quality.

2.2 Materials and Methods

We conducted field trials in 2002 and 2003 at multiple sites in central Alberta. In 2002 there were 3 locations: Ellerslie, Leduc, and Westlock; in 2003 there were 4 locations: Ellerslie, Calmar, Edmonton, and Redwater (Table 2.2.1). Fertility levels were adjusted to 150 kg ha^{-1} N; 120 kg ha^{-1} P_2O_5; 150 kg ha^{-1} K_2O approximate levels based on previous crop rotation, and cooperator soil testing. Fertilizer was broadcast prior to seeding and incorporated using a field cultivator. In 2003, 25 kg ha^{-1} additional N was applied and incorporated in-crop at the V6 stage by row cultivator.

Moisture availability during the 2002 season was limiting, with widespread crop failures in small grain cereals and oilseeds in the region (Table 2.2.2). In 2002 Edmonton received only 32% of the normal growing season rainfall with 100mm from January to July, the lowest amount ever recorded in 119 years (AAFRD 2002). Maize displayed leaf rolling and nitrogen deficiency in the lower leaves due to extreme dry conditions in the upper soil profile. Despite this, trials produced harvestable yields. In 2003 moisture levels were closer to normals for the region (Table 2.2.2) resulting in far lower visible moisture stress, and greater yields.

The experiments were seeded into conventionally tilled land using a mechanical 2-row corn seeder using 76cm row spacing. Plots were 5m x 5m, and consisted of 6 rows to prevent inter-plot interference (David et al 2001) with 30cm between plots. Plots were over-seeded by 20% of the target population and hand thinned at the V4 stage to ensure desired and even plant populations. The entire experiment was surrounded by border plots. Weed control was accomplished using pesticide specific to the unique issues of each location, using a three point hitch field sprayer or hand boom. Mechanical row cultivation and hand weeding was also employed in some instances (Appendix B).

The experimental design was a randomized complete block with four blocks. Four commercially available Pioneer Hi Bred Ltd early maize hybrids were evaluated. These conventional hybrids were among the earliest hybrids developed by Pioneer Hi-Bred: 39N03 (2000 CHU), 39F45 (2000 CHU), 39W54 (2100 CHU), 39T68 (2250 CHU). These hybrids ranged from 2000 CHU to 2250 CHU maturity rating and also varied in physical characteristics such as plant height (Appendix A). Plant population treatments were 49 000, 74 000, 99 000, and 124 000 plants ha^{-1}. The 16 hybrid x population treatments were randomized within each complete block. Agronomic observations were recorded throughout the growing season. Emergence counts were recorded on the center two rows of each plot prior to thinning. Growth rate was measured by the Purdue method (Nielsen 2004) by recording days to the V1, V3, and V6 stage. Onset of the reproductive phase was recorded as days to anthesis (pollen shed in 50% of the plants in the middle 2 rows of each plot) and time to silk emergence (silk 1 cm emerged in 50% of the plants in the middle 2 rows of each plot).

Harvest was done following a killing frost. Harvest was preceded by trimming plot length to 4m. Four randomly chosen plants were then selected from the center two rows to use for dry matter percentage calculation and for quality analysis. The remainder of the middle two rows was hand harvested and weighed to determine yield. Two of the randomly selected plants were weighed and then dried whole in a forced air drier for 30 days at 60°C. They were then separated into cob and stover fraction and weighed to determine dry matter percentage and cob to stover ratio. The other two randomly selected plants were rendered using a chipper to produce chopped silage. The entire sample was then frozen, weighed and shipped to the Pioneer Hi Bred livestock nutrition center in Polk City IA for drying, grinding and NIR analysis (Stuth et al. 2003).

Quality analysis by NIR provided data for a number of forage quality parameters: Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), Crude Protein (CP), Starch content (STR), Invitro digestibility (24 hour) (IVD), dry matter (DMR), Ash, Digestibility of NDF (DNDF). From these values, calculations were performed to determine predicted animal performance based on forage quality data using the Milk2000 spreadsheet (Shaver et al 2000, version 7.54; Undersander et al 1993). Performance parameters calculated using the Milk2000 included: starch digestibility, starch digestion factor, NFC (% of DM), Sugars and VFA's, TDN (% of DM), Net Energy Intake (Mcals kg^{-1}), milk per tonne ($t\ t^{-1}$), and milk per hectare ($t\ ha^{-1}$).

Data were analyzed by location to determine if trends were consistent across environments (Appendix C). Data were then combined and analyzed in the Proc Mixed Procedure of SAS Statistical Software (SAS Institute Inc. 1999). In 2002, the Westlock site experienced cool spring temperatures followed by a frost at the V2 stage that resulted in death of emerged leaves. This was followed by herbicide injury caused by Buctril© herbicide, likely the result of a high degree of cold stress following application. As a result this location was dropped from further analysis. For the purpose of analysis, plant population and hybrid were considered fixed effects with block and environment considered random. Model effects are considered significant when $P<0.05$. Orthogonal contrasts were used to determine if there was a linear, cubic or quadratic relationship between population treatments ($P<0.05$) (SAS Institute Inc. 1999).

2.3 Results

2.3.1 Environmental means for yield and plant development

The six environments differed ($P < 0.01$) for emergence, early growth, flowering, dry matter yield and percent dry matter (Table 2.3.1). Growth and maturity measurements varied greatly across environments. Site mean dry matter yields in 2002 were roughly one half those recorded in 2003, symptomatic of the severe drought experienced in 2002. On average, experimental sites emerged four days later in 2002 and yielded less than 50 % dry matter of those grown in 2003 (Table 2.3.1). The Ellerslie 2002 site exhibited the longest planting to silk emergence interval and exhibited the lowest average yield of all six trials. Ellerslie in 2003 reached the silking stage latest of all four sites; while the two earliest sites (Calmar and Parkland) had the greatest average yield (Table 2.3.1). Maturity at harvest also exhibited large differences between locations, with a 6.7% difference in average dry matter percentage between the highest and lowest locations.

Silage quality was not analyzed on 2002 experimental material. The four 2003 locations differed ($P<0.01$) for all quality traits except simple sugar percentage (Table 2.3.2). Average crude protein percentage was relatively low at all sites (6.3 to 7.3 %), but feeding quality was quite high.

2.3.2 Yield, Maturity and developmental traits

Though average dry matter yield in 2002 was less than one half that of 2003, when traits were analyzed by site and compared, the main effects of hybrid and plant population remained relatively similar (Appendix C). The two 2000 CHU hybrids (39F45 and 39N03) were the earliest to silk and had the highest dry matter percentage at harvest at all six sites, and exhibited lowest dry matter yield at three of three sites where the main effect of hybrid differed ($P < 0.05$) for yield. It was therefore decided to analyze and present mean data for all six sites from MIXED PROCEDURE analyses of SAS (SAS Institute Inc. 1999) where sites and their interactions were considered random and the treatment effects fixed. This allows one to draw inference about the experiment for the 16 plant population × hybrid combinations tested when grown in central Alberta.

Hybrid × plant population interaction effects were not significant ($P > 0.05$) for any agronomic trait recorded except days to V3 (Table 2.3.3 and days to V3 data not shown). Hybrids differed ($P < 0.01$) for days to V1, days to silking, dry matter % and dry matter yield. The hybrid 39W54 (2100 CHU) was the latest flowering, had the least percent dry matter at harvest and was the highest yielding hybrid tested (Table 2.3.3). The two 2000 CHU hybrids 39F45 and 39NO3 were the earliest to flower, had the greatest percent dry matter at harvest and were the two lowest yielding hybrids, with approximately 10% less dry mater yield than 39W54 (Table 2.3.3). The population main effect was significant ($P< 0.05$) for all agronomic traits measured except days to V6 (V6 data not shown). Plant population main effect was linear ($P< 0.05$) for all traits (Table 2.3.3). Thus, increasing plant density from 49,000 to 124,000 plants ha^{-1} resulted in linear increases in days to developmental stages (emergence, V1, V3, and silking) dry matter yield and decrease in dry matter percentage(Table 2.3.3). Densities of 124,000 plants/ha resulted in earliest days to emergence, the latest flowering date, the greatest harvest moisture content and the highest dry matter yield.

2.3.4 Silage quality determinants 2003

Hybrid × plant population interaction effects were not significant (P>0.05) for any of the quality traits measured (Table 2.3.4). Hybrids differed for all quality traits (P<0.01) (Table 2.3.3). The 2000 CHU hybrids 39N03 and 39F45 had the highest percentage cob and starch content while 39W54, the latest maturing hybrid, had the lowest. Acid detergent fiber and neutral detergent fiber were the lowest in the 2000 CHU hybrids 39N03 and 39F45 and the highest in 39W54 (Table 2.3.3). Plant population main effects were significant (P<0.05) for all quality traits except NDF digestibility (DNDF) and whole plant digestibility. The plant population effect was linear (P<0.05) for all quality traits except DNDF (Table 2.3.3). The cob to stover ratio decreased as population increased as did starch content, protein and whole plant digestibility of the silage (Table 2.3.3). Neutral detergent fiber, ADF and simple sugars increased linearly as the plant population increased.

Calculated milk values using the Milk2000 spreadsheet (version 7.54) (Shaver et al 2000) combine yield and quality into a single term for comparison of multiple experimental treatments. Calculated milk yield ha^{-1} exhibited a significant hybrid × plant population treatment interaction effect (P<0.05) (Table 2.3.5). The 2000 CHU hybrid early variety 39N03 grown at 99 000 plants ha^{-1} had the highest calculated milk yield and the highest percent dry matter of all hybrids tested. All hybrids exhibited a decrease in milk yield t^{-1} of forage fed as the population density increased. Conversely, yields increased linearly with population density (P<0.05).

2.4 Discussion and Conclusion

An adapted variety as defined by Troyer and Brown (1976) flowers late enough to provide adequate plant size but early enough to complete grain filling in an average season. For silage maize production, whole plant moisture content of 60%-70% with a fully formed cob is considered mature (OMFRA 2002). During the 2002 and 2003 growing season the CHU accumulation at Ellerslie (Table 2.2.2) was very close to the long term average of 2050 CHU (AAFRD 2005), while precipitation was 41% and 75 % of normal in 2002 and 2003 respectively. All hybrids tested achieved a maturity in the 60%-70% moisture content range at all six sites under all four plant population densities. Thus all four low CHU hybrids tested in this experiment appear to be adapted for silage production in central Alberta, and all could be considered for production in this region. It would appear that breeding for early maturity maize hybrids will now allow for the expansion of silage maize production onto the northern Canadian prairies.

Environmental variability on the prairies is a major source of variation in yield for well adapted crops such as barley (Yang et al. 2006). Maize, a crop at the very limit of its northern adaptation in central Alberta, is likely to be affected by a number of environmental factors in this region. Corn Heat Units available in central Alberta average 2050 CHU (AAFDR 2005), however studies in Ontario indicate CHUs can fluctuate widely on a year to year basis (Brown and Bootsma 1995). Season length is variable and the timing of frost can fluctuate in both the spring and fall (AAFRD 1998). Temperatures may be too cool for optimal growth (Major and Hamilton 1978) and cold temperatures may result in chilling injury (Fryer et al 1995).

Despite plantings from the beginning of May to May 13th, all trials emerged, on average, during the last week of May, seemingly more dependent on environmental conditions than the date of planting. This resulted in average emergence for all trials being later than the normal date of last spring frost (AAFRD 1998), thus decreasing the risk of frost damage to young seedlings. Low temperatures following planting may actually provide benefit in affording a wider range of planting dates without increasing the associated risk of frost damage.

Available soil moisture in the prairies is generally limiting to crop yields (McGinn and Shepard 2003) and in Manitoba was determined to be the most limiting abiotic factor determining maize yield (Hamilton et al. 1976). In the drought year of 2002 yields averaged only 45% of the 2003 yields. Plants also reached the silking stage later in the drought year. Although drought stress forced maturation of all trials in 2002, all trials in both years matured adequately for silage production prior to the first killing frosts. During 2002 and 2003 seasons, sub-normal precipitation (41% in 2002, 75% in 2003) was available for crop growth. Nevertheless, average maize trial yields during the present experiment were more than four times (424%) the average oat and three times (336%) the average barley forage yields for Alberta in 2002 (AAFRD 2005). The 2002 maize yields recorded during this experiment occurred during widespread crop failures (AAFRD 2005), and thus maize appeared capable of providing some marketable yield even during a year of extreme abiotic stress.

In the present experiment the 2000 CHU hybrids evaluated yielded the greatest dry matter at densities of 99 000 plants ha^{-1}. Although they did not yield as much dry matter as the 2100 and 2250 CHU hybrids, they did have dry matter percentages around 40 % at harvest, even at the highest plant densities. As a result the 2000 CHU hybrids 39F45 and 39N03 planted at densities of 99 and 124 000 plants ha^{-1} could provide the best yield, balanced with the most nutritive feed in most years in central Alberta. In general, increasing plant density has been reported to delay flowering, resulting in greater moisture content at harvest, especially in northern maize growing regions (Olson 1971; Alessi and Power 1974; Modarres et al. 1998; Fairey 1983). The results of the present study corroborate such reports. The 2000 CHU hybrids we tested evidently pose a lower risk associated with achieving adequate dry matter percentage in years falling below the average CHU accumulation. Conversely, in years that have above average CHU accumulation, later maturing (2100 to 2250 CHU) hybrids (39T68, 39W54) would have a higher yield potential than early maturing hybrids, making better use of increased CHU through longer lifecycles and larger plant size (Troyer 2001). Later maturing hybrids resulted in higher dry matter yields than did early maturing hybrids in this study.

In both Troyer and Brown's (1976) and OMFRA's (2002) definition, grain filling is an important factor in maturity. In comparing hybrids the 2000 CHU hybrids we tested had a much greater proportion of whole plant dry matter in the cob compared with later hybrids. Observation of grain filling confirmed that early hybrids were more advanced in grain filling than later maturing hybrids at the time of killing frost. Lower CHU hybrids exhibited greater adaptation to the region, achieving higher yields as plant density increased, with acceptable (>30%) dry matter percentages for ensiling. Higher CHU hybrids (≥ 2100 CHU) display less adaptation to central Alberta, exhibiting decreased yield at higher plant densities and less than optimal dry matter percentage (< 30%) for ensiling. The hybrids 39W54 (2100 CHU) and 39F45 (2000 CHU) tested in the present experiment exhibited very different yield and maturity, despite having the same Corn Relative Maturity (CRM) as rated for the Corn Belt in the mid-west of the United States (Troyer 2001). Thus, the central Alberta environment poses different criterion for maturity than the environments used to classify these hybrids into CRM. This suggests the need for local agronomic testing before silage maize hybrids can be recommended at any given seeding rate in central Alberta.

2.5 Summary

New maize (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. To maximize productivity and evaluate potential of this new cropping option, agronomic evaluation of new hybrids is needed in this environment. Field experiments were conducted in central Alberta at seven locations between 2002 and 2003. Silage yield, maturity and quality response was evaluated for four short-season Pioneer hybrids varying in maturity from 2000 to 2250 Corn Heat Units. Increasing plant density from ~50 000 to ~124 000 plants/ha^{-1} delayed silking by 5 days. Silage dry matter percentage at harvest ranged from 35% to 31% DM from low to high density, respectively. Yield increased linearly ($P < 0.05$) with increased plant density. Lower (2000) corn heat unit hybrids exhibited a greater adaptation to the region. They yielded more dry matter with acceptable (>30%) dry matter for ensiling as plant density increased. Higher corn heat unit varieties displayed less adaptation to central Alberta, exhibiting decreased yield at higher plant densities with less than optimal dry matter percentage (< 30%) and associated quality characteristics for ensiling.

2.6 Tables

Table 2.1 List and description of sites along with planting dates of seven trials planted in 2002 and 2003 in central Alberta

Location	Latitude[z]	Longitude[z]	Soil Type[y]	Elevation[x]	Plant Hardiness Zone[W]	Avg date fall frost [U]	Avg Date Spring Frost [U]	Precipitation (Annual) [V]	Planting Date (2002)	Planting Date 2003
Ellerslie	53.42	113.49 W	Black Chernozemic	694m	3a	11-Sep	25-May	460mm	4-May	8-May
Leduc	53.20	113.91 W	Black Solonetzic	723m	3a	10-Sep	24-May	482mm	10-May	-
Westlock	54.06	113.64 W	Black Chernozemic	650m	2b	17-Sep	22-May	520mm	10-May	-
Calmar	53.26	113.81 W	Black Chernozemic	720m	3a	15-Sep	22-May	521mm	-	12-May
Edmonton	53.52	113.50 W	Black Chernozemic	671m	3a	21-Sep	10-May	477mm	-	8-May
Redwater	53.91	113.16 W	Black Chernozemic	642m	3a	18-Sep	14-May	463mm	-	13-May

[z] - Natural Resources Canada (2005) The atlas of Canada. http://atlas.gc.ca/site/english/index.html Accessed April 2 2005

[y] - Agriculture Canada (2001). CanSIS - Canadian soil information system. Version 2.2 (2001). http://sis.agr.gc.ca/cansis/nsdb/slc/webmap.html Accessed April 2 2005

[x]- Environment Canada (2004). Canadian Climate normals 1971-2000. http://www.climate.weatheroffice.ec.gc.ca/climate_normals/stnselect_e.html Accessed April 2 2005

[W] - Agriculture Canada (2000). Plant Hardiness zones of Canada. http://wms1.agr.gc.ca/cgi-bin/mapplant2000?mode=browse&layer=zones&layer=cities Accessed April 2 2005

[V] - Environment Canada (2004) Precipitation Data - Environment Canada Canadian Climate Normals or averages http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html

[U] - AAFRD (1998) Freezing date probabilities Source: Agdex 075-2. Revised January 1998. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10?opendocument

Table 2.2 Ellerslie weather station data for accumulated precipitation and crop heat units (CHU) in 2002 and 2003

Precipitation (mm)	May	Jun	July	Aug	Sept	Total	% Normal
2002 [y]	7	31.6	37.4	46.8	12	134.8	41%
% Normal	16%	37%	41%	78%	24%		
2003 [y]	52	53	81.4	45.4	16.2	248	75%
% Normal	122%	62%	88%	76%	33%		
Normal (1971-2000) [z]	42.5	85.4	92.1	60.1	49.3	329.4	100%

Corn Heat Units (CHU)	May	Jun	July	Aug	Sept	Total	% Normal
2002 [y*]	180	542	600	484	229	2035	99%
2003 [y**]	234	439	628	618	210	2129	104%
Normal (1971-2000) [x]						2050	100%

z - Environment Canada (2004) Canadian climate normals or averages 1971-2000
http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html Accessed April 20 2006

y- Ellerslie Meteorological Station - University of Alberta

x- AAFRD (2005) Forage Corn: Silage or winter grazing.
http://www1.agric.gov.ab.ca/$department/newslett.nsf/all/wfbg7469 Accessed April 20 2006

* 2002 - killing frost Sept 22
** 2003 - killing frost Sept 15

Table 2.3 Means of agronomic traits, maturity, and yield averaged over four hybrid and four plant population treatments for 6 sites grown in central Alberta in 2002 and 2003[z]

Environment	Days to Emergence[y]	Days to V1	Days to Silk	Dry Matter (%)	Dry Matter Yield (t/ha)
2002 Ellerslie	22	24	96	35.8	5.1
2002 Leduc	19	24	89	29.1	7.3
2003 Calmar	17	22	82	35.2	14.9
2003 Ellerslie	17	21	87	35.7	13.5
2003 Redwater	13	17	85	32.9	12.4
2003 Edmonton	17	21	82	34.2	13.9
Mean	18	21	87	33.8	11.2
SE Diff	0.1	0.1	2.1	0.01	0.32
P value **	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV %	0.3	3	14	12	16

** - P-value effects significant at P<0.01

[y] - For planting dates please refer to table 2.2.1

Table 2.4 Means of quality traits, maturity, yield, and calculated milk yield averaged over four maize hybrid and four plant population treatments grown in four sites in Central Alberta in 2003.

Location (2003)	Dry matter yield (tonnes/ha)	Dry matter (%)	Cob weight (% of plant)	Neutral Detergent Fiber (NDF)	Acid detergent Fiber (ADF)	Crude Protein (%)	Starch (%)	Digestibility NDF (24h)	Invitro digestibility (whole plant)	Simple sugars (%)	Ash (%)	Milk Per tonne (tonnes)	Milk Per Ha (tonnes)
Calmar	14.9	35	41	44	23	6.3	19	47	72	15	4	1.1	15.9
Ellerslie	13.5	36	46	42	21	6.7	20	48	73	16	4	1.2	15.5
Redwater	12.4	33	38	46	25	6.9	16	48	70	14	5	1.1	13.4
Edmonton	13.9	34	45	40	21	7.3	22	48	73	15	5	1.2	16.6
Mean	13.7	35	43	43	22	6.8	19	48	72	15	4	1.1	15.4
SE diff	0.26	0.0	0.9	0.5	0.3	0.01	0.8	0.3	0.3	0.5	0.1	0.02	0.45
P Value	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	0.0724 ns	<0.0001 **	<0.0001 **	<0.0001 **

ns,** : not significant (P≥ 0.01) and P-value effects significant (P<0.01) respectively

Table 2.5 Simple effect means of agronomic traits, maturity, and yield for four hybrid and four plant populations grown in six sites in Central Alberta in 2002, 2003.

	Days to emergence[y]	Days to V1	Days to Silking	Dry Matter (%)	Dry Matter Yield (tonnes/Ha)
Hybrid					
39F45	17	21	79	36.6	10.7
39N03	17	21	86	36.9	10.6
39T68	18	21	90	31.6	11.6
39W54	18	22	92	30.2	11.9
SE diff	0.1	0.2	3.2	0.01	0.37
Population (plants/ha)					
49000	18	22	84	35.3	10.0
74000	18	21	86	33.8	11.1
99000	17	21	88	33.7	11.7
124000	17	21	89	32.5	12.0
SE diff	0.1	0.1	1.3	0.01	0.51
F-test					
Hybrid	0.0672 ns	<.0001 **	0.0052 **	<.0001 **	0.0059 **
Plant Population	0.0381 *	0.042 *	0.0002 **	0.0137 *	0.0084 **
Hybrid x Population	0.3412 ns	0.0793 ns	0.9997 ns	0.2914 ns	0.1233 ns
Contrasts (Population)[z]					
Linear	0.0271 *	0.0058 **	<.0001 **	0.0022 **	0.0012 **

z - All quadratic and cubic contrasts non-significant ($P \geq 0.01$)
y - For plant dates refer to table 2.2.1
ns, *, ** : effects non-significant, effects significant at $P<0.05$ level, effects significant at $P<0.01$ level respectively

Table 2.6 Simple effect means for silage quality data derived by NIR analysis for four hybrids and four plant populations for four sites grown in Central Alberta in 2003[x].

	Percent Cob (% Whole Plant)	Neutral Detergent Fiber (NDF)	Acid Detergent Fiber (AFD)	Crude Protein (%)	Starch (%)	Digestibility NDF (DNDF)	Invitro Digestibility (Whole Plant)	Simple Sugars (%)
Hybrid								
39F45	49	42.2	22	6.6	24	47.9	72.6	12
39N03	48	42.0	22	7.1	25	48.3	72.7	11
39T68	38	43.7	23	6.6	15	47.1	71.7	19
39W54	35	45.0	24	6.9	14	48.2	71.3	18
SE diff	1.1	0.48	0.3	0.00	1.0	0.33	0.34	0.7
Population (Plants ha^{-1})								
49000	47	42.3	22	7.0	21	48.2	72.6	14
74000	45	42.8	22	6.8	20	47.8	72.3	14
99000	41	43.4	23	6.8	19	47.6	71.9	15
124000	38	44.5	23	6.6	17	47.8	71.5	17
SE diff	1.5	0.65	0.4	0.01	0.8	0.33	0.37	0.6
F-tests[z]								
Hybrid	<0.0001 **	<0.0001 **	<0.0001 **	0.0002 **	<0.0001 **	0.0044 **	<0.0001 **	<0.0001 **
Population	0.0013 **	0.0391 *	0.0315 *	<0.0001 **	<0.0001 **	0.4019 ns	0.0677 ns	0.0001 **
Hybrid x Pop	0.0761 ns	0.5567 ns	0.9178 ns	0.11287 ns	0.6547 ns	0.8903 ns	0.6214 ns	0.5137 ns
Contrasts[y]								
Linear	0.0002 **	0.0066 **	0.0047 **	<0.0001 **	<0.0001 **	0.2208 ns	0.0113 *	<0.0001 **

z-ns, *, ** : effects non-significant, effects significant at P<0.05 level, effects significant at P<0.01 level respectively
y- All quadratic and cubic contrasts non-significant

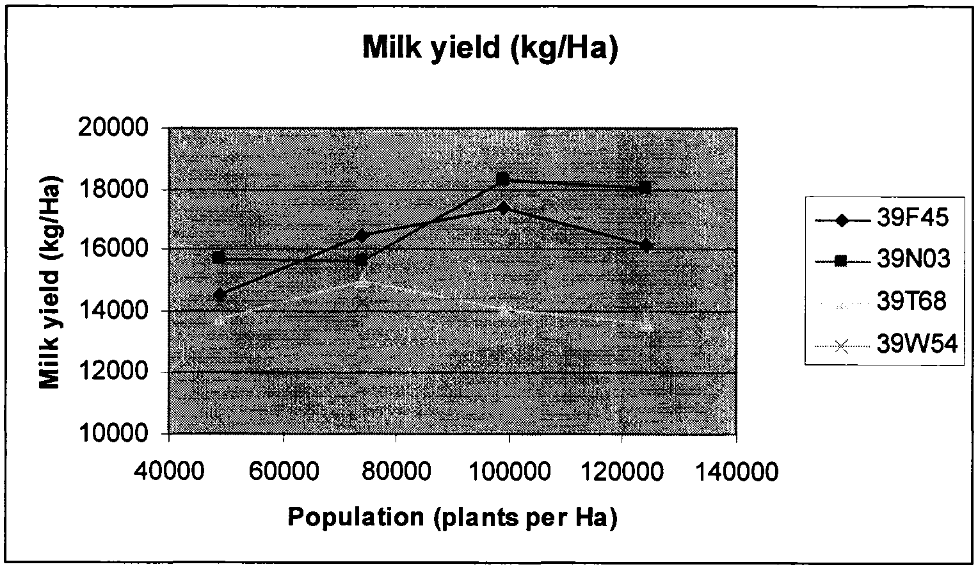
Table 2.7 Factorial means for four hybrids x four populations of calculated milk yield, milk production per tonne of forage, yield and dry matter percentage for four locations in central AB in 2003.

Hybrid	Plant Population (Plants ha^{-1})	Dry Matter yield (t ha^{-1})	Dry Matter (%)	Milk Per tonne of forage (tonnes)	Milk Per ha^{-1} (tonnes)
39F45	49000	11.2	38.2	1.3	14.5
	74000	12.8	37.4	1.3	16.5
	99000	13.8	37.8	1.3	17.4
	124000	13.6	35.1	1.2	16.1
39N03	49000	11.2	37.9	1.4	15.7
	74000	12.1	36.1	1.3	15.6
	99000	13.4	38.7	1.3	18.3
	124000	14.4	36.9	1.2	18.0
39T68	49000	12.8	33.5	1.1	13.7
	74000	14.4	33.2	1.1	15.0
	99000	15.4	31.8	0.9	14.0
	124000	15.6	31.4	0.9	13.6
39W54	49000	13.3	32.5	1.1	14.2
	74000	14.5	31.4	1.0	14.2
	99000	14.7	30.7	1.0	14.4
	124000	15.8	29.9	0.9	14.1
SE diff		0.58	0.96	0.07	1.23
F-test[z]	Hybrid	0.0002 **	<0.0001 **	<0.0001 **	0.0002 **
	Population	0.005 **	0.0397 *	<0.0001 **	0.294 ns
	Hybrid x Pop	0.1129 ns	0.0076 **	0.4524 ns	0.0229 *
Contrasts[y]	Linear	0.0007 **	0.011 *	<0.0001 **	0.1652 ns

z-ns, *, ** : effects non-significant, effects significant at P<0.05 level, effects significant at P<0.01 level respectively
y- All quadratic and cubic contrasts non-significant (P≥ 0.05)

2.7 Figures

Figure 2.1 Calculated milk yields (kg ha^{-1}) of four hybrids at four populations grown in Central Alberta in 2003



Standard errors and associated statistics for this figure are presented in Table 2.7

2.8 Literature Cited

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Chapter 3
The effect of row spacing and hybrid on maize silage yield and quality in central Alberta

3.1 Introduction

New maize (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. Agronomic evaluation of new hybrids is needed in this environment to maximize productivity and evaluate potential of this new cropping option. Decreasing row spacing from 76cm to narrow 38cm row widths may result in an increased rate of canopy closure and decreased intra-row competition. This would improve the competitive ability of maize in this region where maize is poorly adapted. Likely, improved competition for resources during cool spring temperatures will enhance yields and may decrease time to maturity in this season limiting environment.

Optimal row widths in field maize production have become increasingly narrow as plant densities have increased resulting in higher yields (Duvic and Cassman 1999). Maize grown at a given population, when grown at narrow row spacing, intercepts a greater proportion of the incident radiation, increases LAI, and increases the efficiency of light interception (Bullock et al 1988). Under low population densities, narrow row spacing allows for a more equidistant planting arrangement and has been reported to improve light attenuation (Maddonni et al 2001). More equidistant planting in narrow row spacing can decrease stress from interplant competition for nutrients, thereby increasing yields (Barbieri, 2000).

Hybrid genotype can affect the response to narrow row production and there have been reports of significant hybrid genotype × row spacing interactions (Farnham 2001). Maddonni et al. (2001) reported that some hybrids were unable to adjust leaf distribution to accomodate interplant shading competition, while others exhibited a great deal of flexibility. Studies in the northern US have shown less hybrid × row spacing interactions, with narrow row spacing having distinct yield advantages (Porter et al 1997; Cox et al 1998). It may be that hybrids adapted to northern environments are also innately adapted to narrow row spacing. Hybrids adapted to temperate environments are short in stature, have lower leaf area and are source limited (Hunter 1980). Inability of the crop to reach critical leaf area index (95% light interception) was the main criterion listed by Maddonni (2001) for improved light interception from narrow row spacing.

In a summary of research on narrow row spacing Gray (1999) reported a 6.2% advantage for narrow row corn in the northern US. This advantage diminished as trials moved further south with a reported 4.1% yield disadvantage conferred by narrow row spacing in the southern US (Grey 1999, In: Farnham 2001). A similar result was reported in a research summary by Paskiewicz (1997), who noted an 8% yield advantage in narrow row production for locations above 44° N compared with only a 4% overall advantage. Other studies have reported that narrow row spacing under adequate fertility resulted in grain yield increases of <10% (Bullock et al 1988, Porter et al 1997). Lambert and Lowenberg-DeBoer (2001) reported that maize yield increases were inconsistent, with increases in stalk breakage and management costs associated with narrow rows. Narrow row spacing exhibited a greater yield response under low fertility conditions than under optimal fertility (Barberi et al 2000).

The objectives of the present experiment were to determine the effect of hybrid and row spacing on maize growth rate, yield, and maturity in central Alberta. Results from this experiment may be used for the development of better adapted hybrids, and for a basis in the design of further agronomic research. Recommendations may also be made available to producers for optimal yield production for silage maize production in central Alberta.

3.2 Materials and Methods

We conducted field trials in 2002 and 2003 at multiple locations in central Alberta. In 2002, trials were planted at Ellerslie and Leduc; the experimental sites in 2003 were Ellerslie and the University Farm in Edmonton. Descriptions of these sites were provided in Table 2.2.1. Planting dates differed from the trials reported upon in Chapter 2. Thus planting dates for trials of the present study were May 1 (2002) and May 23 (2003) at Ellerslie, May 10 (2002) at Leduc, and May 24 (2003) in Edmonton. Fertility application and general agronomic treatment of the trials has been described previously in Chapter 2. Climatic data for the trials was also described previously (Table 2.2.2).

The experimental design was a split plot with four replicates. Row spacing treatment constituted the main plot with hybrid as the sub-plot. Five commercially available Pioneer Hi Bred Ltd early maize hybrids were evaluated: 39N03, 39F45, 39W54, 39M27 and 39T68. These hybrid varieties varied in maturity ranging from 2000 CHU to 2250 CHU maturity rating (Appendix A). The experiments were seeded into conventionally tilled land using a mechanical plot seeder. Plot size for all treatments was 5 m long × 5 m wide. Plots were over-seeded by 20% of the target population and hand thinned at the V4 stage to ensure desired population at even within row intervals between plants. The entire experiment was surrounded by border plots to prevent edge effects.

Row spacing treatments used in the experiments were 76cm and 38cm row spacing. The 76cm row spacing is conventionally used in much of the maize growing acreage in North America. The 38 cm row spacing allows more equidistant planting with an average of 30cm intra-row spacing at 74000 plants ha^{-1} spacing compared with 15cm in 76cm row spacing plantings. Agronomic observations for the trials were recorded as described in Chapter 2. Likewise, forage quality analyses were performed as described in Chapter 2 for experimental material harvested in 2003 only.

Data were analyzed in the Proc MIXED Procedure of SAS Statistical Software (SAS Institute Inc. 1999). For the purpose of analysis, row spacing treatments and hybrid were considered fixed effects with block and environment considered random. Model effects are considered significant when $P<0.05$ (SAS Institute Inc. 1999).

3.3 Results

3.3.1 Environmental means for yield and plant development

The four environments differed ($P < 0.01$) for emergence, early growth, flowering, dry matter yield and percent dry matter (Table 3.3.1). Growth and maturity measurements varied greatly across environments. Site mean dry matter yields in 2002 were <40% of those recorded in 2003, symptomatic of the severe drought experienced in 2002 (Table 3.3.1). . Because experiments were seeded much earlier in 2002, this resulted in experiments emerging four days earlier on average in 2002. The Ellerslie 2002 site exhibited the longest planting to silk emergence interval and exhibited the lowest average yield of all four trials. Ellerslie in 2003 reached the silking stage later than Edmonton and exhibited the highest average yield of all four sites (Table 3.3.1). Maturity at harvest also exhibited large differences between locations, with a 4.6% difference in average dry matter percentage between the highest and lowest locations.

Silage quality was not analyzed on 2002 experimental material. The two 2003 locations differed ($P<0.01$) for neutral detergent fiber and acid detergent fiber as well as protein (Table 3.3.2). Average crude protein percentage was relatively low at all sites (6.6 to 7.3 %), but feeding quality was quite high.

3.3.2 Yield, Maturity and developmental traits

Average dry matter yield in 2002 was less than one half that of 2003. Due to the large differences, 2002 and 2003 data were analyzed separately, employing the MIXED PROCEDURE analyses of SAS (SAS Institute Inc. 1999) where sites and their interactions were considered random and the treatment effects fixed. Hybrid × row width interaction effects were not significant ($P > 0.05$) for any agronomic trait recorded in 2002 (Table 3.3.3) or 2003 (Table 3.3.4). The two 2000 CHU hybrids (39F45 and 39N03) were the earliest to silk and had the highest dry matter percentage at harvest in both years(Table 3.3.3 & Table 3.3.4). Hybrids did not differ ($P>0.05$) for dry matter yield either 2002 or 2003. In 2002, hybrids differed ($P < 0.05$) for days to emergence, V1, V3, V6, days to silking, and dry matter %. In 2003, hybrids differed ($P < 0.05$) for days to V3, days to silking, and dry matter %. In 2002 the row spacing main effect was not significant ($P < 0.05$) for any agronomic traits measured except days to emergence (Table 3.3.3). In 2003, the row spacing main effect was significant ($P<0.05$) only for days to silk emergence (Table 3.3.4).

3.3.4 Silage quality determinants 2003

Hybrid × row width interaction effects were not significant ($P>0.05$) for any of the quality traits measured in 2003 (Table 3.3.5). Hybrids differed for crude protein and starch, ($P<0.01$) (Table 3.3.5). The 2000 CHU hybrids 39N03 and 39F45 had the highest starch content while 39W54, the latest maturing hybrid, had the lowest. Row spacing main effects were not significant ($P<0.05$) for any quality traits measured.

Calculated milk values using the Milk2000 spreadsheet (version 7.54) (Shaver et al 2000) combine yield and quality into a single term for comparison of multiple experimental treatments. Hybrid × plant population treatment interaction effects were not significant ($P<0.05$) for either of the calculated milk values (Table 3.3.5). Hybrids differed for milk per tonne of forage fed and for calculated milk yield per hectare ($P<0.01$) (Table 3.3.5). The 2000 CHU hybrid early variety 39N03 had the highest calculated milk yield and the highest percent dry matter of all hybrids tested. Row spacing effect was significant ($P<0.01$) for milk yield per hectare. Narrow row (38cm) maize produced 1.9 tonnes ha-1 higher calculated milk yield than did conventional (76cm) row width (Table 3.3.5)

3.4 Discussion and Conclusion

An adapted variety as defined by Troyer and Brown (1976) flowers late enough to provide adequate plant size but early enough to complete grain filling in an average season. For silage maize production, whole plant moisture content of 60%-70% with a fully formed cob is considered mature (OMFRA 2002). During the 2002 and 2003 growing season the CHU accumulation at Ellerslie (Table 2.2.2) was very close to the long term average of 2050 CHU (AAFRD 2005), while precipitation was 41% and 75 % of normal in 2002 and 2003 respectively. Later maturing hybrids 39T68, 39W54 and 39M27 failed to achieve a maturity in the 60%-70%

moisture content range in all environments. Early (2000CHU) hybrids 39N03 and 39F45 achieved acceptable maturity of 60%-70%. Thus the low CHU hybrids tested in this experiment appear to be better adapted for silage production in central Alberta, while the later hybrids are less well adapted or poorly adapted, though all could be considered for production in this region. It would appear that breeding for early maturity maize hybrids will now allow for the expansion of silage maize production onto the northern Canadian prairies.

Environmental variability on the prairies is a major source of variation in yield for well adapted crops such as barley (Yang et al. 2006). Maize, a crop at the very limit of its northern adaptation in central Alberta, is likely to be affected by a number of environmental factors in this region. Corn Heat Units available in central Alberta average 2050 CHU (AAFDR 2005), however studies in Ontario indicate CHUs can fluctuate widely on a year to year basis (Brown and Bootsma 1995). Season length is variable and the timing of frost can fluctuate in both the spring and fall (AAFRD 1998). Temperatures may be too cool for optimal growth (Major and Hamilton 1978) and cold temperatures may result in chilling injury (Fryer et al 1995).

Despite plantings from the beginning of May to May 24th, all trials emerged, on average, during the last week of May, seemingly more dependent on environmental conditions than the date of planting. This resulted in average emergence for all trials being later than the normal date of last spring frost (AAFRD 1998), thus decreasing the risk of frost damage to young seedlings. Low temperatures following planting may actually provide benefit in affording a wider range of planting dates without increasing the associated risk of frost damage.

Available soil moisture in the prairies is generally limiting to crop yields (McGinn and Shepard 2003) and in Manitoba was determined to be the most limiting abiotic factor determining maize yield (Hamilton et al. 1976). In the drought year of 2002 yields averaged only 40% of the 2003 yields. Plants reached the silking stage later in the drought year as well. Although drought stress forced maturation of all trials in 2002, all trials in both years, on average, matured adequately for silage production prior to the first killing frosts. During 2002 and 2003 seasons, sub-normal precipitation (41% in 2002, 75% in 2003) was available for crop growth. Nevertheless, average maize trial yields during the present experiment were three and a half times (360%) the average oat and nearly three times (280%) the average barley forage yields for Alberta in 2002 (AAFRD

2005). The 2002 maize yields we recorded during this experiment occurred during widespread crop failures (AAFRD 2005), and thus maize appeared capable of providing some marketable yield even during a year of extreme abiotic stress.

In the present experiment the 2000 CHU hybrids evaluated yielded the greatest dry matter percentage averaged across row widths. Yields of these lower CHU hybrids did not differ from the later maturing longer season hybrids in either year. As a result the 2000 CHU hybrids 39F45 and 39N03 could provide the greatest yield, balanced with the most nutritive feed, in most years in central Alberta. Optimal row width in maize production has resulted in a number of studies indicating yield advantages in narrow row production (Porter et al 1997; Cox et al 1998). Although dry matter yield and dry matter percentage did not show any statistical advantage ($P>0.05$) in narrow row production, there was a 19% yield advantage present in 2003 and a 33% advantage in 2002. This resulted in a measurable advantage ($P<0.01$) for predicted milk yield in narrow row spacings of 38 cm. Narrow row spacing resulted in a predicted 1.9 t ha^{-1} advantage ($P < 0.01$) in milk yield, resulting in a predicted increase of 16% milk over the conventional 76cm row spacing. This is similar to other reports of the yield advantage of narrow row spacing in northern environments (Paskiewicz, 1997; Gray, 1999).

3.5 Summary

New maize (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. Field experiments were conducted in central Alberta at four environments in 2002/2003. Silage yield, maturity and quality response was evaluated for five short-season Pioneer hybrids varying in maturity from 2000 to 2250 Corn Heat Units. Altering row spacing from 76 to 38 cm with a constant plant density ~74 000 plants ha^{-1} did not alter ($P > 0.05$) any agronomic or quality trait except predicted milk produced per t dry matter. Narrow row spacings are predicted to produce more ($P < 0.01$) milk than the standard spacing of 76 cm. Lower (2000) CHU hybrids exhibited a greater adaptation to the region than those rated greater than 2000 CHU. They yielded more dry matter with acceptable (>30%) dry matter for ensiling at both row spacing levels. It is possible to grow high yielding and acceptable quality silage maize in central Alberta using 2000 CHU hybrids developed in eastern North America.

3.6 Tables and Figures

Table 3.1 Environment means of yield, maturity and agronomic traits for five maize hybrids grown at 38cm and 76cm row width at 74000 plants ha^{-1} at four sites in Central Alberta in 2002 and 2003

Environment	Days to Emergence	Days to V1	Days to V3	Days to V6	Days to silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
2002 Ellerslie	29	34	44	55	104	33.6	3.8
2002 Leduc	20	25	34	45	95	29.0	6.7
2003 Ellerslie	10	15	28	44	77	32.0	14.2
2003 Edmonton	12	17	25	42	73	29.7	12.7
Mean	18	23	33	46	85.8	30.9	10.4
SE Diff	0.1	0.1	0.1	0.2	0.3	0.01	0.41
P Value (environment)	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	<0.0001 **	0.001 **	<0.0001 **

ns, *, ** : effects non-significant, effects significant at P<0.05 level, effects significant at P<0.01 level respectively
^ For sowing dates refer to table 3.2.1

Table 3.2 Environment means of silage quality, yield, maturity and calculated milk yield for five maize hybrids grown at 38cm and 76cm row width at 74000 plants ha^{-1} at two sites in Central Alberta in 2003.

Location (2003)	Dry matter yield (tonnes/ha)	Dry matter (%)	Neutral Detergent Fiber (NDF)	Acid detergent Fiber (ADF)	Crude Protein (%)	Starch (%)	Milk Per tonne (tonnes)	Milk Per Ha (tonnes)
Ellerslie	14.2	32	46	24	6.6	11	0.9	13.0
Edmonton	12.7	30	42	22	7.3	13	1.0	12.5
Mean	13.4	31	44	23	6.9	13	1.0	12.8
SE diff	0.34	0.4	0.5	0.3	0.10	0.8	0.00	0.50
P Value (environment)	0.054	0.0162	0.0001	0.0003	0.0005	0.0913	0.0535	0.4433

ns,** : not significant (P≥ 0.01) and P-value effects significant (P<0.01) respectively

Table 3.3 Means for seven agronomic and yield traits of five maize hybrids at 38cm and 76cm row spacing grown at 74000 plants ha^{-1} for two sites grown in Central Alberta in 2002.

Hybrid	Days to Emergence	Days to V1	Days to V3	Days to V6	Days to silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	24	28	38	49	94	33.9	5.2
39M27	25	30	40	51	102	29.2	4.8
39N03	24	29	39	49	97	34.3	5.4
39T68	24	29	39	50	101	30.8	5.4
39W54	25	31	40	50	103	28.2	5.4
SE Diff	0.2	0.4	0.5	0.4	0.0	1.76	0.64
P Value (Hybrid)	0.0163	0.0171	0.0485	0.0009	0.0097	0.0266	0.7975
	*	*	*	**	**	*	ns

Row Width	Days to Emergence	Days to V1	Days to V3	Days to V6	Days to silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
38	25	29	39	50	98	31.6	6.0
76	24	29	39	50	100	31.0	4.5
SE Diff	0.1	0.1	0.1	0.8	0.1	1.28	0.38
P Value (Row width)	0.0317	0.6069	0.052	0.541	0.0711	0.689	0.1674
	*	ns	ns	ns	ns	ns	ns

P Value (Hybrid x row width)	0.0558	0.1355	0.94	0.7215	0.8115	0.684	0.2681
	ns	ns	ns	ns	ns	ns	ns

ns, *, ** : effects non-significant, effects significant at $P<0.05$ level, effects significant at $P<0.01$ level respectively

^ For sowing dates refer to materials and methods

Table 3.4 Means for seven agronomic and yield traits of five maize hybrids at 38cm and 76cm row spacing grown at 74000 plants ha^{-1} for two sites grown in Central Alberta in 2003.

Hybrid	Days to Emergence	Days to V1	Days to V3	Days to V6	Days to silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	11	16	26	42	73	33.0	12.9
39M27	11	16	27	44	77	30.2	13.3
39N03	11	16	26	42	73	34.1	13.2
39T68	11	16	26	43	77	29.0	14.0
39W54	11	16	27	43	78	28.1	13.8
SE Diff	0.1	0.3	0.2	0.6	0.4	0.76	0.51
P Value (Hybrid)	1	0.5	0.0021	0.2694	0.0007	0.005	0.2185
	ns	ns	**	ns	**	**	ns

Row Width	Days to Emergence	Days to V1	Days to V3	Days to V6	Days to silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
38	11	16	26	42	75	31.2	14.6
76	11	16	26	43	76	30.6	12.3
SE Diff	0.1	0.2	0.1	0.7	0.2	0.46	0.76
P Value (Row width)	1	0.5	1	0.4405	0.0169	0.4321	0.2065
	ns	ns	ns	ns	*	ns	ns
P Value (Hybrid x Row width)	1	0.5	0.1612	0.4581	0.8986	0.8035	0.6897
	ns	ns	ns	ns	ns	ns	ns

ns, *, ** : effects non-significant, effects significant at P<0.05 level, effects significant at P<0.01 level respectively
^ For sowing dates refer to table 3.2.1

Table 3.5 Means for seven silage quality, yield and calculated milk yield traits of five maize hybrids at 38cm and 76cm row spacing grown at 74000 plants ha^{-1} for two sites grown in Central Alberta in 2003.

Hybrid	Neutral Detergent Fiber (NDF)	Acid Detergent Fiber (ADF)	Crude Protein (%)	Starch (%)	Dry Matter Yield (t/ha)	Milk per tonne as fed (tonnes)	Milk yield per ha (tonnes)
39F45	43.4	22.7	6.7	15.2	12.9	1.0	13.6
39M27	45.2	23.4	6.8	11.2	13.3	0.9	11.9
39N03	41.9	21.7	7.2	19.7	13.2	1.2	15.8
39T68	44.7	22.9	6.8	8.6	14.0	0.8	11.1
39W54	45.7	23.3	7.2	7.7	13.8	0.8	11.4
SE Diff	1.16	0.74	0.16	1.95	0.51	0.05	0.80
P Value (Hybrid)	0.0671	0.2227	0.0032	0.0003	0.2185	0.0004	<0.0001
	ns	ns	**	**	ns	**	**

Row Width	Neutral Detergent Fiber (NDF)	Acid Detergent Fiber (ADF)	Crude Protein (%)	Starch (%)	Dry Matter Yield (t/ha)	Milk per tonne as fed (tonnes)	Milk yield per ha (tonnes)
38	44.4	23.1	6.9	12.2	14.6	0.9	13.7
76	44.0	22.5	7.0	12.8	12.3	1.0	11.8
SE Diff	1.07	0.72	0.10	1.06	0.76	0.03	0.50
P Value (Row width)	0.7435	0.5343	0.4618	0.6172	0.2065	0.3993	0.0004
	ns	ns	ns	ns	ns	ns	**
P Value (Hybrid x Row width)	0.9523	0.9775	0.7571	0.499	0.6897	0.4562	0.6877
	ns	ns	ns	ns	ns	ns	ns

ns, *, ** : effects non-significant, effects significant at P<0.05 level, effects significant at P<0.01 level respectively
^ For sowing dates refer to table 3.2.1

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Chapter 4.0 General Conclusions

New maize hybrids between CHU ratings of 2000 and 2200 have been developed for short season environments which may be capable of achieving silage maturity in central AB. Agronomic evaluation of early maize varieties is necessary to determine potential, and to uncover optimum management practices in Alberta. The central AB environment poses a number of challenges to maize production. The season length is short, ranging from a frost-free period of 109 days at the Edmonton international airport to 132 days at the Namao airport. The climate is cooler than current maize growing regions. Cool conditions reduce the rate of crop development, making the season length limiting in most years. Information on growth and development of the crop, and subsequent yield, maturity and quality were unavailable in central AB prior to this thesis work.

The objectives of this thesis research were:

1) To evaluate the effect of hybrids of varied maturity ratings, planted at a range of plant densities, on yield, maturity and quality in central Alberta.
2) To determine the effect of row spacing on yield, maturity and quality.
3) To determine if silage maize is a potential cropping option for central Alberta

The null hypotheses tested through this thesis research were:

1) Hybrids of varied maturity ratings grown at varied plant densities will not differ for yield, maturity or quality.
2) Altered spatial planting arrangements do not alter maize yield, maturity, or quality.

The following points from the two research chapters developed from these objectives summarizes the general conclusions derived from this thesis work:

Chapter 2

- Maize hybrids rated between 2000 and 2250 CHU will reach silage maturity in central Alberta in normal years.
- Maize hybrids rated 2000 are more adapted to central Alberta than those rated with greater CHU. 2000 CHU hybrids tend to silk earlier than later hybrids and reach a greater percentage of dry matter by the time autumn frosts necessitate harvest than later hybrids. Though these

hybrids do not yield as much dry matter as hybrids rated greater than 2000 CHU, they tend to have better forage quality, which translates into greater milk production per hectare.

- Increasing plant density from ~50 000 to ~124 000 plants ha^{-1} delayed silking by 8 days. Yield increased linearly ($P < 0.05$) with increased plant density. Silage dry matter percentage at harvest ranged from 35% to 31% DM from low to high density, respectively.
- Lower (2000) corn heat unit hybrids exhibited a greater adaptation to the region. They yielded more dry matter with acceptable (>30%) dry matter for ensiling as plant density increased.
- Higher corn heat unit varieties displayed less adaptation to central Alberta, exhibiting decreased yield at higher plant densities with less than optimal dry matter percentage (< 30%) and associated quality characteristics for ensiling.

Chapter 3

- Maize hybrids rated between 2000 and 2250 CHU will reach silage maturity in central Alberta in normal years.
- Maize hybrids rated 2000 are more adapted to central Alberta than those rated with greater CHU. 2000 CHU hybrids tend to silk earlier than later hybrids and reach a greater percentage of dry matter by the time autumn frosts necessitate harvest than later hybrids. Though these hybrids do not yield as much dry matter as hybrids rated greater than 2000 CHU, they tend to have better forage quality, which translates into greater milk production per hectare.
- A narrow row spacing of 38 cm (as opposed to the standard 76 cm) at a constant plant density of 74,000 plants ha^{-1} did not alter ($P > 0.05$) any agronomic or quality trait. Nevertheless, a combined result of no statistically significantly greater dry matter percentage and yield at harvest resulted in greater milk yield per ha for the narrow row spacings of 38 cm
- Lower (2000) corn heat unit hybrids exhibited a greater adaptation to the region. They yielded more dry matter with acceptable (>30%) dry matter for ensiling as plant density increased.
- Higher corn heat unit varieties displayed less adaptation to central Alberta, exhibiting decreased yield at higher plant densities with less than optimal dry matter percentage (< 30%) and associated quality characteristics for ensiling.

General Conclusions:

Maize hybrids used in this study rated 2000 to 2250 CHU will reach silage maturity in central Alberta and can be considered for production in this region. As such, these hybrids met the definition of adapted maize by achieving a minimum of 30% dry matter (Major and Hamilton 1978). The early maturing 2000 CHU were more adapted with a more fully formed ear, a criterion in the Ontario agriculture definition of adapted maize hybrids (OMFRA 2002). The early hybrids tended to silk earlier and had higher starch content by harvest. The early 2000 CHU hybrids also had a higher dry matter content at harvest. When forage quality was examined using the Milk 2000 model (Shaver et al. 2000 version 7.54; Undersander et al. 1993) the early hybrids had better predicted performance than later maturing hybrids. Early 2000 CHU hybrids had higher predicted milk per ha yield than late hybrids, despite lower dry matter yields. Early hybrids had a lower dry matter yield than later maturing hybrids. This effect would be more pronounced in years with above average CHU accumulation, as later (2100-2250 CHU) hybrids would be able to better utilize the longer season.

Plant density increases within the range of 49,000 to 124,000 plants ha^{-1} resulted in increased yields, however resulted in a decrease in the indicators of adaptation (Major and Hamilton 1978; OMFRA 2002) decreasing percent dry matter and starch content. Increasing plant density delayed silking of hybrids decreasing the remaining CHU for grain filling. This resulted in decreased ear development with lower starch content and diminished percent dry matter at harvest. This also resulted in decreases in predicted output using the Milk 2000 model (Shaver et al. 2000 version 7.54; Undersander et al. 1993). High densities showed a decrease in milk output per tonne of forage fed. Optimum plant density was dependant on hybrid, balancing yield increases with forage quality decreases. Early hybrids (2000CHU) were more tolerant of higher density than later hybrids (2100-2250 CHU), as developmental delays had less of an effect on forage quality. This was the result of a higher degree of maturity achieved by the early hybrids in the season limited environment of central Alberta.

Future works to improve the productivity of maize include further agronomic studies such as the effects of fertility on yield and development of maize hybrids. Additional research on the effect of plant date across a number of years would be beneficial to optimizing maize in this environment. Further efforts in the breeding of better adapted hybrids that optimally utilize the central Alberta conditions would likely provide better adaptation. As maize is a potential option for producers of central Alberta, the use of information from this study and future studies should be used to develop an Alberta maize production guide to allow producers to realize maximum benefit from maize production.

A general recommendation would be to plant 2000 CHU hybrids with planting densities of 99,000 to 124,000 plants ha^{-1} in central Alberta. When tested at 74,000 plants ha^{-1} narrow row spacing of 38cm gave an advantage in milk yields and may be employed to achieve acceptable maize silage quality in central Alberta. The central Alberta environment poses different criterion for maturity than the environments used to classify maize hybrids into Corn Relative Maturity ratings. This suggests the need for local agronomic testing before silage maize hybrids can be recommended at any given seeding rate in central Alberta.

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5.0 Appendices

Appendix A: Description of maize hybrids used in thesis

Hybrid	Heat unit	RM	Yield for mat	adapt to high pop	adapt to low pop	grain drydown	stalk strength	root strength	staygreen	drought tol	test wt	early growth	plant ht	husk cover	mid seson brittle
39N03	2000	72	6	x	x	5	4	5	4	6	6	6	5	5	6
39F45	2000	73	6	x	x	6	3	4	4	5	6	7	5	4	
39W54	2100	73	7	7	6	6	5	4	4	5	6	5	6	5	X
39T68	2250	77	8	8	7	5	5	4	4	6	6	6	6	6	5
39M27	2150	77	8	8	x	6	3	5	4	5	7	4	5	5	x

9= excellent, 1= poor x= insufficient data

Adapted from: Hybrid descriptions in: Pioneer Growing Point Website
http://www.pioneer.com/growingpoint/default_en.jsp

Appendix B - Chemical weed control measures for Experiment 1,2,3 and 4 in 2002 and 2003 at 8 sites in Central Alberta

Date	Location	Experiment[z]	Herbicide	Rate (ha^{-1})	Corn Stage	Application method	Weed species present
April 30 2002	Ellerslie	E1,E2,E3	Eradicane	5000ml	Pre-plant	Soil incorporated	stinkweed, volunteer canola,shepards purse
June 20 2002	Westlock	E1,E2,E3	Buctril M	1000ml	V2	Field sprayer	Narrow leafed hawksbeard, hempnettle, wild oats, perenial sow thistle, volunteer canola
June 27 2002	Leduc	E1,E2,E3	Decis	200ml	V4	Field sprayer	Cutworms, grasshoppers
May 1 2003	Ellerslie	E1,E2,E3	Primextra	3500ml	Pre-plant	Soil incorporated	
May 1 2003	Calmar	E1,E2	Primextra	3500ml	Pre-plant	Soil incorporated	
May 27 2003	Leduc	E4	Primextra	3500ml	Pre-plant	Extend seeder	
May 29 2003	Ellerslie	E1,E2,E3	Roundup	1250ml	V1	backpack spot sray	Canada thistle, quackgrass
June 4 2003	Ellerslie	E3	Lontrel	850ml	hypocotyl	backpack hand boom	Canada thistle, Dandelion
June 4 2003	Ellerslie	E1, E2	Lontrel	850ml	V1	backpack spot spray	Canada thistle
June 4 2003	Redwater	E1	Lontrel	850ml	V2	backpack hand boom	Canada thistle
June 6 2003	Edmonton	E2	2,4-D	600ml	V2	backpack hand boom	stinkweed, shepards purse
June 9 2003	Calmar	E1,E2	Accent	35g	V2	backpack hand boom	volunteer wheat
June 10 2003	Ellerslie	E1,E2	Accent	35g	V3	backpack spot sray	quackgrass
June 12 2003	Ellerslie	E1,E2,E3	2,4-D	550ml	V3	backpack hand boom	stinkweed, volunteer canola,shepards purse
June 12 2003	Edmonton	E1, E3	2,4-D	550ml	V3	backpack hand boom	stinkweed, shepards purse
June 16 2003	Calmar	E1,E2	Lontrel	850ml	V3	backpack hand boom	thistle, dandelion
June 17 2003	Ellerslie	E1,E2,E3	Decis	200ml	V4	Field sprayer	Cutworms, Army cutworm
June 28 2003	Redwater	E1	Lontrel	850ml	V5	backpack hand boom	Canada thistle
July 3 2003	Ellerslie	E3	Lontrel	850ml	V5	backpack hand boom	Canada thistle
July 3 2003	Leduc	E4	Lontrel	850ml	V3	backpack hand boom	Canada thistle
July 18 2003	Leduc	E4	Lontrel	850ml	V6	backpack hand boom	Canada thistle

z- Experiment 1: The effect of hybrid and population density on yield and quality of silage maize in central Alberta (Chapter 2)
Experiment 2:The effects of CRM and plant date on yield and maturity of silage corn in Central Alberta (Poster Appendix E)
Experiment 3: The effect of row spacing and hybrid on maize silage yield and quality in central Alberta (Chapter 3)
Experiment 4: Information sheet "The use of clear plastic mulch film for corn production in the very short season of central Alberta" (Appendix H)

Appendix C: Agronomic and Yield data means of hybrids and treatments by environment of experiment 1: Effect of hybrid and density on yield and maturity of silage in Central Alberta

Ellerslie 2002

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	22	147	24	36	49	88	39.6%	5.4
39N03	21	146	24	37	48	95	40.8%	5.1
39T68	22	147	24	38	50	100	32.9%	4.6
39W54	22	147	25	38	50	103	29.9%	5.4
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.208
SE Diff	0.2	0.2	0.2	0.3	0.3	0.7	1.13%	0.40

Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	22	147	24	37	49	91	40.3%	5.4
74000	22	147	24	37	49	95	35.5%	5.4
99000	22	147	24	37	49	99	34.5%	4.9
124000	22	147	24	37	50	102	32.9%	4.7
Contrasts								
Linear	0.0335	0.0335	0.0029	0.6407	<0.0001	<0.0001	<0.0001	0.0473
Cubic	0.8979	0.8979	0.5312	0.4641	0.1106	0.5874	0.2174	0.5345
Quadratic	0.3915	0.3915	0.1651	0.6546	0.0455	0.0893	0.0575	0.7338
P value	0.1504	0.1504	0.0116	0.8087	0.0001	<0.0001	<0.0001	0.2132
SE Diff	0.2	0.2	0.2	0.3	0.3	0.7	1.13%	0.40

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	22	147	24	37	49	81	44.7%	6.1
39F45	74000	22	147	24	36	48	85	39.6%	5.7
39F45	99000	22	147	24	37	49	90	38.7%	4.6
39F45	124000	22	147	24	36	49	97	35.5%	5.4
39N03	49000	22	147	24	37	48	88	47.1%	5.2
39N03	74000	22	147	24	38	48	94	39.8%	4.7
39N03	99000	22	147	24	37	48	99	39.6%	6.0
39N03	124000	21	146	23	37	49	100	36.5%	4.6
39T68	49000	22	147	24	38	49	95	36.6%	5.1
39T68	74000	22	147	24	38	49	100	32.2%	4.8
39T68	99000	22	147	24	38	50	102	31.6%	4.5
39T68	124000	22	147	24	38	51	104	31.1%	4.3
39W54	49000	22	147	25	38	50	99	32.6%	5.4
39W54	74000	23	148	26	38	50	100	30.4%	6.5
39W54	99000	22	147	25	39	50	105	28.2%	4.8
39W54	124000	22	147	25	38	50	106	28.4%	4.8
P value		0.8979	0.898	0.1151	0.4662	0.2905	0.0009	0.7224	0.321
SE Diff		0.4	0.4	0.4	0.8	0.8	1.9	3.20%	1.14

Appendix C continued...

Leduc 2002

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	19	150	23	33	46	64	31.8%	7.3
39N03	19	150	24	34	46	94	31.2%	7.1
39T68	19	150	24	34	47	97	26.8%	7.0
39W54	20	151	25	35	48	99	26.8%	7.6
P value	<0.0001	<0.0001	<0.0001	<0.0001	0.0022	0.0003	<0.0001	0.4396
SE Diff	0.1	0.1	0.2	0.2	0.6	8.2	0.87%	0.40

Plant Population (Plants ha-1)	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	19	150	24	34	47	85	29.4%	6.3
74000	20	151	25	34	47	88	29.4%	7.4
99000	19	150	24	34	47	90	29.0%	7.7
124000	19	150	24	34	47	91	28.8%	7.7
Contrasts								
Linear	0.0111	0.0111	0.0238	0.5979	0.3113	0.4627	0.3945	0.0005
Cubic	0.0046	0.0046	0.0082	0.4824	0.7344	0.9753	0.7774	0.755
Quadratic	0.4627	0.4627	0.6367	0.4325	0.4493	0.9193	0.8594	0.0614
P value	0.0027	0.0027	0.0081	0.7044	0.6295	0.9049	0.8368	0.0016
SE Diff	0.1	0.1	0.2	0.2	0.6	8.2	0.87%	0.40

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	19	150	23	33	46	59	33.7%	6.5
39F45	74000	19	150	24	33	47	64	31.0%	6.5
39F45	99000	19	150	24	33	46	67	31.7%	7.9
39F45	124000	19	150	23	34	47	68	30.7%	8.2
39N03	49000	19	150	24	34	46	92	31.3%	5.8
39N03	74000	20	151	24	34	46	93	33.0%	7.2
39N03	99000	19	150	24	34	46	95	29.0%	7.1
39N03	124000	19	150	24	34	46	95	31.6%	8.2
39T68	49000	20	151	25	35	47	96	26.6%	5.2
39T68	74000	20	151	25	35	48	97	26.2%	7.4
39T68	99000	19	150	23	34	47	97	27.0%	7.6
39T68	124000	19	150	24	34	47	98	27.3%	7.9
39W54	49000	20	151	25	35	47	96	26.0%	7.5
39W54	74000	20	151	25	35	46	98	27.5%	8.2
39W54	99000	20	151	25	35	48	100	28.2%	8.2
39W54	124000	20	151	25	36	50	104	25.4%	6.6
P value		0.6777	0.6777	0.2247	0.1488	0.2678	1	0.2446	0.0566
SE Diff		0.3	0.3	0.5	0.6	1.6	23.3	2.46%	1.13

Appendix C continued...

Calmar 2003

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	17	150	22	29	69	78	37.5%	14.7
39N03	17	150	22	30	51	79	38.1%	13.5
39T68	17	150	22	30	51	85	33.2%	15.5
39W54	17	150	22	30	51	86	32.2%	15.9
P value	0.5061	0.5061	0.2469	<0.0001	0.4074	<0.0001	<0.0001	0.0002
SE Diff	0.2	0.2	0.2	0.2	13.2	0.4	0.74%	0.51

Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	17	150	22	30	69	79	35.9%	13.5
74000	17	150	22	30	50	81	36.0%	14.8
99000	17	150	22	30	51	83	35.4%	15.4
124000	17	150	22	30	51	84	33.6%	15.7
Contrasts								
Linear	0.8549	0.8549	0.851	0.0731	0.2203	<0.0001	0.0024	<0.0001
Cubic	0.5838	0.5838	0.5736	0.1755	0.6448	0.3861	0.8673	0.8208
Quadratic	0.4151	0.4151	1	0.6105	0.3237	0.2277	0.0833	0.1732
P value	0.7977	0.7977	0.9484	0.1531	0.4395	<0.0001	0.0075	0.0004
SE Diff	0.2	0.2	0.2	0.2	13.2	0.4	0.74%	0.51

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	16	149	21	29	125	76	38.8%	13.1
39F45	74000	17	150	22	30	51	77	38.6%	14.9
39F45	99000	17	150	22	29	51	78	38.0%	16.1
39F45	124000	17	150	22	30	51	82	34.6%	14.7
39N03	49000	17	150	22	29	50	77	38.2%	12.6
39N03	74000	17	150	22	30	50	78	37.7%	12.7
39N03	99000	17	150	22	30	52	80	39.7%	14.3
39N03	124000	16	149	21	30	51	82	36.9%	14.4
39T68	49000	17	150	22	31	50	82	34.3%	13.5
39T68	74000	17	150	22	31	50	84	33.8%	15.5
39T68	99000	16	149	21	30	51	87	33.1%	16.4
39T68	124000	17	150	22	31	51	87	31.8%	16.5
39W54	49000	17	150	22	30	50	83	32.5%	14.8
39W54	74000	17	150	22	30	51	86	34.0%	16.2
39W54	99000	17	150	22	31	51	87	30.9%	15.0
39W54	124000	17	150	23	31	52	87	31.3%	17.4
P value		0.0798	0.0798	0.0292	0.3555	0.4526	0.037	0.4142	0.3095
SE Diff		0.6	0.6	0.6	0.5	37.5	1.0	2.10%	1.45

Appendix C continued...

Ellerslie 2003

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	17	146	20	33	54	83	39.4%	12.6
39N03	17	146	20	32	53	86	37.6%	12.6
39T68	17	146	21	33	53	89	33.6%	14.8
39W54	17	146	21	33	54	91	32.0%	14.0
P value	-	-	<0.0001	0.0005	0.2054	<0.0001	<0.0001	<0.0001
SE Diff	0	0	0.2	0.2	0.2	0.3	0.81%	0.42

Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	17	146	21	33	53	85	36.1%	12.1
74000	17	146	21	33	53	87	36.0%	13.2
99000	17	146	21	33	54	88	35.3%	14.2
124000	17	146	21	33	54	89	35.2%	14.5
Contrasts								
Linear	-	-	0.5328	0.0007	0.0001	<0.0001	0.2177	<0.0001
Cubic	-	-	0.835	0.8413	0.6279	0.6444	0.6773	0.6294
Quadratic	-	-	0.6417	0.1836	0.2809	0.3044	0.9873	0.1615
P value	-	-	0.8823	0.0045	0.001	<0.0001	0.6314	<0.0001
SE Diff	0	0	0.2	0.2	0.2	0.3	0.81%	0.42

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	17	146	20	32	53	81	39.7%	10.9
39F45	74000	17	146	21	32	54	83	39.2%	12.5
39F45	99000	17	146	21	33	54	84	40.3%	14.0
39F45	124000	17	146	20	33	55	85	38.4%	13.1
39N03	49000	17	146	21	32	53	84	37.5%	11.1
39N03	74000	17	146	20	32	53	86	37.5%	12.1
39N03	99000	17	146	20	32	54	86	37.0%	13.0
39N03	124000	17	146	20	33	54	88	38.6%	14.2
39T68	49000	17	146	21	33	53	87	33.6%	13.3
39T68	74000	17	146	20	33	53	89	35.3%	14.9
39T68	99000	17	146	21	33	54	90	32.5%	15.4
39T68	124000	17	146	21	33	54	91	32.9%	15.6
39W54	49000	17	146	22	33	53	89	33.6%	13.0
39W54	74000	17	146	22	33	54	90	31.8%	13.4
39W54	99000	17	146	21	33	54	91	31.6%	14.6
39W54	124000	17	146	22	34	54	93	31.1%	15.1
P value		-	-	0.9454	0.3361	0.9052	0.7965	0.6149	0.8132
SE Diff		0	0	0.5	0.6	0.7	1.0	2.28%	1.20

Appendix C continued...

Redwater 2003

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	13	147	17	33	49	82	34.7%	11.2
39N03	13	147	17	33	49	83	35.1%	11.9
39T68	13	147	17	33	49	86	31.4%	13.0
39W54	13	147	17	33	49	87	30.5%	13.7
P value	0.108	0.108	0.2179	0.0899	0.4744	<0.0001	<0.0001	<0.0001
SE Diff	0.1	0.1	0.2	0.2	0.3	0.4	0.56%	0.40

Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	13	147	18	33	49	83	33.6%	9.7
74000	13	147	17	33	49	84	31.9%	11.5
99000	13	147	17	33	49	86	33.5%	14.0
124000	13	147	17	33	49	86	32.5%	14.5
Contrasts								
Linear	0.516	0.516	0.025	0.0206	0.0345	<0.0001	0.3721	<0.0001
Cubic	0.8282	0.8282	0.8593	0.6646	0.7569	0.0328	0.0019	0.0522
Quadratic	0.628	0.628	0.2379	0.3343	0.7293	0.9001	0.4151	0.0307
P value	0.8693	0.8693	0.0923	0.0899	0.1896	<0.0001	0.0113	<0.0001
SE Diff	0.1	0.1	0.2	0.2	0.3	0.4	0.56%	0.40

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	13	147	17	33	49	81	34.5%	8.5
39F45	74000	13	147	17	32	49	80	34.1%	10.5
39F45	99000	13	147	17	33	50	84	36.3%	12.5
39F45	124000	13	147	17	34	50	84	33.7%	13.2
39N03	49000	13	147	18	32	49	81	35.7%	9.2
39N03	74000	13	147	17	33	49	83	32.6%	10.4
39N03	99000	13	147	17	33	49	84	36.1%	13.0
39N03	124000	13	147	18	33	49	85	36.0%	14.9
39T68	49000	13	147	18	33	49	85	32.1%	10.0
39T68	74000	13	147	17	33	49	87	31.4%	11.9
39T68	99000	13	147	17	33	49	87	31.2%	15.7
39T68	124000	13	147	17	33	49	87	31.0%	14.5
39W54	49000	13	147	18	33	49	86	32.1%	11.2
39W54	74000	13	147	18	33	49	87	29.7%	13.3
39W54	99000	13	147	18	33	49	88	30.6%	14.7
39W54	124000	13	147	17	33	50	89	29.4%	15.5
P value		0.5558	0.5558	0.1225	0.1403	0.319	0.0235	0.1264	0.2473
SE Diff		0.3	0.3	0.6	0.5	0.7	1.0	1.58%	1.13

Appendix C continued...

Edmonton 2003

Hybrid	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	17	146	20	32	50	78	36.9%	12.9
39N03	17	146	20	32	50	78	38.7%	13.2
39T68	17	146	20	33	50	84	31.6%	14.9
39W54	17	146	21	34	50	86	29.8%	14.7
P value	-	-	<0.0001	<0.0001	0.9007	<0.0001	<0.0001	<0.0001
SE Diff	0	0	0.1	0.2	0.3	0.3	0.49%	0.31

Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
49000	17	146	21	33	50	80	36.4%	13.2
74000	17	146	20	33	50	81	34.0%	14.3
99000	17	146	21	33	51	82	34.7%	13.7
124000	17	146	20	33	51	84	31.8%	14.6
Contrasts								
Linear	-	-	0.4078	0.0036	<0.0001	<0.0001	<0.0001	0.0008
Cubic	-	-	0.1016	0.0861	0.3156	0.0145	0.0001	0.0017
Quadratic	-	-	0.5365	0.1481	0.8622	0.0433	0.4847	0.6236
P value	-	-	0.2884	0.005	<0.0001	<0.0001	<0.0001	0.0002
SE Diff	0	0	0.1	0.2	0.3	0.3	0.49%	0.31

Hybrid	Population (Plants ha^{-1})	Days to Emergence	Date of Emergence	Days to V1	Days to V3	Days to V6	Days to 50% silk emergence	Dry Matter (%)	Dry Matter Yield (t/ha)
39F45	49000	17	146	20	32	50	76	39.9%	12.5
39F45	74000	17	146	20	32	50	78	37.7%	13.3
39F45	99000	17	146	21	32	51	78	36.7%	12.6
39F45	124000	17	146	21	33	51	81	33.5%	13.4
39N03	49000	17	146	21	32	50	77	40.0%	11.9
39N03	74000	17	146	20	32	50	78	36.4%	13.3
39N03	99000	17	146	20	32	51	79	42.2%	13.4
39N03	124000	17	146	20	33	51	80	36.1%	14.1
39T68	49000	17	146	21	33	50	82	34.2%	14.3
39T68	74000	17	146	20	33	50	83	32.1%	15.4
39T68	99000	17	146	21	33	50	84	30.3%	14.2
39T68	124000	17	146	20	33	51	88	29.8%	15.8
39W54	49000	17	146	21	33	50	84	31.6%	14.1
39W54	74000	17	146	21	34	50	86	30.0%	15.1
39W54	99000	17	146	21	34	51	87	29.6%	14.4
39W54	124000	17	146	21	34	51	89	27.9%	15.0
P value		-	-	0.2259	0.5932	0.9785	0.1634	<0.0001	0.6946
SE Diff		0	0	0.4	0.5	0.7	0.9	1.38%	0.88

The following five appendices include posters which have been presented at various scientific meetings over the last four years. All posters involve research which was conducted during my research as an MSc student at the University of Alberta affiliated with Pioneer Hi-Bred. Some of this research was not written into the present thesis due to time considerations, and thus the posters are presented to outline some of the additional work I conducted during this time.

Appendix D: Poster presentation "The effects of CRM and plant density on yield and maturity of silage corn in Central Alberta

The effects of CRM and plant density on yield and maturity of silage corn in Central Alberta

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Introduction

New corn (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. To maximize productivity and evaluate potential of this new cropping option, agronomic evaluation of new hybrids is needed in this environment. Increasing plant density can result in greater yields, however it also delays maturity. Both yield and maturity must be considered when determining variety and density recommendations for producers.

Our objectives are to determine how variety and density affect development, yield, and maturity in this new environment. The data can be used for the development of better adapted hybrids, and for a basis in the design of further agronomic research. Recommendations can also be made to producers to achieve more optimal yields and consistent maturity despite environmental *variability in this region.*

Materials & Methods

We are evaluating four early Pioneer hybrid maize hybrids (39N03, 39F45, 39W54, 39T68) ranging from 2000 to 2250 corn heat unit maturity rating. These hybrids are being tested in a factorial experiment at 49 000, 74 000, 99 000 and 124 000 plants/Ha in a complete randomized block design with four replicates. In 2002 three locations in central Alberta were evaluated with 4 locations in 2003. Plots are over-seeded mechanically and thinned at V4 stage. Plots measured 5m by 5m with 6 rows spaced at 76cm.

Data is collected for emergence, V3, V6, anthesis, 50% silk emergence. Harvest of the center two rows determined yield. A sub-sample of 4 whole plants are randomly selected to determine dry matter percentage. A rendered whole plant sample is then analyzed by NIR for quality parameters.

Presented data is from the 2002 and 2003 field seasons. Data is analyzed by analysis of variance using the Mixed Model in SAS statistical software. Environments were entered as random effects within the model. A combined analysis of silking date, maturity, and yield indicated no significant interactions between treatments. Mean seperation of treatments was obtained by Fisher's Least Significant Difference (LSD). Regression equations on mean yields at each plant density estimated hybrid yield response. Linear or quadratic equations were selected if regression coefficients were significant ($P=0.05$)

Maturity Ratings

Hybrid	CRM	CHU
39F45	73	2050
39N03	72	2000
39T68	77	2250
39W54	73	2100

POPULATIONS

Plants/acre	Plants/Ha
20000	49000
30000	74000
40000	99000
50000	124000

Acknowledgements

This work is supported by NSERC and Pioneer Hi Bred Production LTD.

Results

Days to 50% silking is significantly different between hybrids and plant densities. ($P<0.05$). Orthogonal contrasts show significant linear response in silking date to plant density ($P < 0.05$)(Figure 1). Average silking date delay of 5.5 days occurred from low to high density across hybrids. (see figure 1)

Maturity level measured by harvest % moisture differed significantly by hybrid ($P < 0.05$) and by density ($P < 0.05$). There was no significant interaction between hybrid and density ($P > 0.05$). Plant density increase resulted in a significant, negative linear response ($P < 0.05$) in maturity (figure 2). By hybrid, the early hybrids (39N03 and 39F45) showed a higher dry matter % at harvest than the later hybrids (39W54 and 39T68). (see figure 2)

Interaction effect of density and hybrid was not significant on yield ($P>0.05$). Yield *varied significantly by both variety and density ($P<0.05$).*

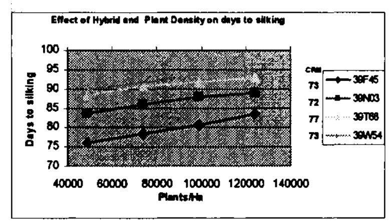

Figure 1. Days to silking Response of Early Hybrids to density

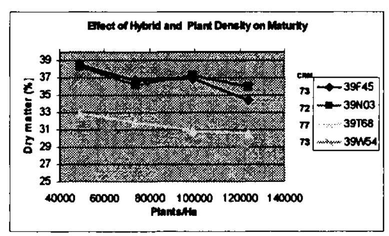

Figure 2. Maturity Response of Hybrids to density

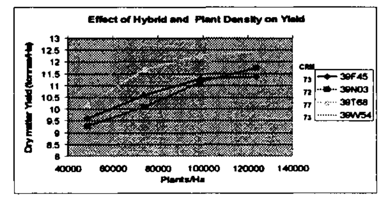

Figure 3. Yield Response of Hybrids to density

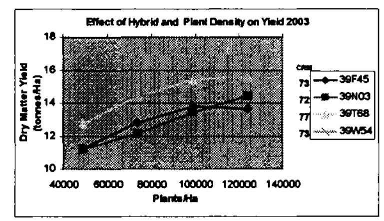

Figure 4. Yield Response of Hybrids to density in 2003: A more typical set of Alberta Environments

Conclusions

- Lower corn heat unit hybrids show a greater adaptation to the region achieving higher yields as plant density increases and acceptable (>30%) dry matter percentages for ensiling.
- Higher corn heat unit hybrids display less adaptation to central Alberta, exhibiting decreased yield at higher plant densities and unacceptable dry matter percentage (< 30%) for ensiling.
- Increasing plant density delays silking and decreases maturity (dry matter %) thus excessive plant density should be avoided as season length is limiting.
- Decreasing plant density of higher heat unit hybrids cannot be used as an alternative to growing lower heat unit, better adapted varieties
- Hybrids 39W54 and 39F45 (CRM 73) showed very different yield and maturity despite having the same CRM. Thus the central Alberta environment poses different criterion for maturity than the environments used to classify these hybrids into CRM

Appendix E: Poster presentation "The effects of CRM and plant date on yield and maturity of silage corn in Central Alberta."

The effects of CRM and plant date on yield and maturity of silage corn in Central Alberta

D. Stanton[1], A.W. Grombacher[2], R. Pinnisch[3], D. Spaner[1]

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Introduction

New corn (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. To maximize productivity and evaluate potential of this new cropping option agronomic evaluation of new hybrids is needed in this environment. The central Alberta environment is typified by cold spring soils, low overall Corn Heat Units (CHU) and a short frost free period. Early planting dates (Late April) have been recommended in attempt to maximize the growing season. Early plant dates place seed into cold soils below the minimum temperature required for growth often for extended periods. These early planted seedlings also face a high probability of spring frost with an average between May 12 and 18 for last day of spring frost in the area. Additionally, once emerged, seedlings receive low CHU resulting in slow growth and low competitive ability. Central Alberta has an average of 2100 CHU thus current hybrids are also limited by fall frost in most years. Another environmental factor is the long daylength during summer months (17 hours June 21). Extended photoperiod may improve growth but may also delay onset of reproductive phase depending on photoperiod sensitivity.

Our objectives are to determine how planting date and hybrid affect development, yield, and maturity in this new environment. Data can be used for the development of better agronomic practices allowing increased realization of corns potential in this environment as well as serve as a foundation for further agronomic research. Recommendations can also be made to producers to achieve more optimal yields and consistent maturity despite environmental variability in this region.

Materials & Methods

We are evaluating four early Pioneer hybrid maize hybrids (39N03, 39F45, 39W54, 39T68) ranging from 2000 to 2250 corn heat unit maturity rating. These hybrids are being tested in a factorial experiment with 4 planting dates: May 1, May 12, May 23, and June 3 in a complete randomized block design with four replicates. Six row plots were seeded to 30000 plants per acre in 17.5 ft rows at 30 inch row spacing. In 2002 two locations in central Alberta were evaluated, with 3 locations in 2003. Plots are over-seeded mechanically and thinned at V4 stage. Plots measured 5m by 5m with 6 rows spaced at 76cm.

Data is collected for emergence counts, V3, V6, anthesis, 50% silk emergence. Harvest of the center two rows determined yield. A sub-sample of 4 whole plants was randomly selected to determine dry matter percentage. A rendered *whole plant sample is then analyzed by NIR for quality parameters.*

Presented data is from the 2003 field season. Data is analyzed by analysis of variance using the General linear Model in SAS statistical software.. Mean separation of treatments was obtained by Fisher's Least Significant Difference (LSD). Regression equations on mean yields at each plant density estimated yield response of hybrids. Linear or quadratic equations were selected if regression coefficients were significant (P=0.05)

Acknowledgements

This work is supported by NSERC and Pioneer Hi Bred Production LTD.

Results

Stand counts indicated a significant loss of plant population on the first planting date (see figure 1). Stand loss averaged 27% for the May 1 plant date in 2003. Days to 50% silking is showed a significant interaction between Hybrids and planting dates (P<0.05) (Figure 2). Silking date remained constant for the first two planting dates (May 1, May 12) and then increased by 4.5 days (May 23) and 7.5 days (June 3). Maturity as determined by harvest moisture showed a significant interaction between hybrid and plant date (P<0.05). Maturity showed a slight improvement from date 1 to date 2 then for the two latter dates dry matter percentage dropped 5% and 5.5% respectively. Dry matter yield did not show significant differences between plant dates (P>0.05).

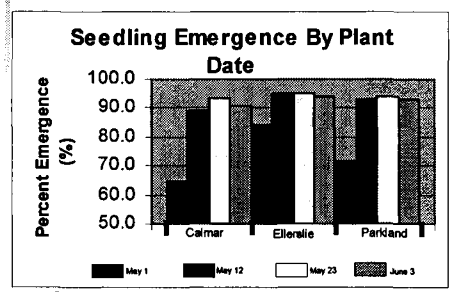

Figure 1. Seedling Emergence by Plant Date for 2003 locations

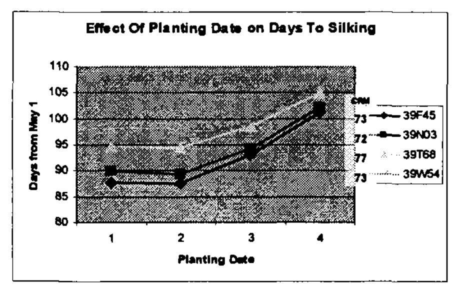

Figure 2. Effect of planting date on days to silking (Days from May 1) 2003

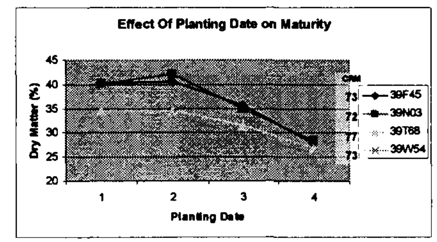

Figure 3. Maturity Response of Hybrids to Planting Date (2003)

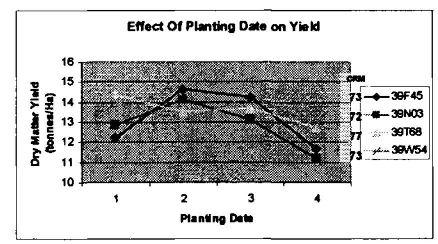

Figure 4. Yield Response of Hybrids to Planting Date in central Alberta 2003

Conclusions

- Early Planting resulted in significant stand losses. These losses were limited to the first planting date (May 1) showing no significant loss in plantings May 11th or later
- When looking at percent dry matter it is evident that the earliest plant date did not give a maturity advantage over the second date however it was preferential to the later two dates.
- Later Hybrids did not suffer yield loss from early planting stand reduction as individual plants compensated for decreased stand better than early hybrids
- It should be noted that the May 11th planting date and later provided more even and more vigorous stands allowing better weed control and more consistent plants at harvest with less tillering.
- Corn in Alberta requires timely planting to minimize the stand losses while ensuring adequate time for maturation

Appendix F: Poster presentation "The effects of row spacing on yield and maturity of silage corn in Central Alberta."

#484

The effects of Row Spacing on Yield and Maturity of Silage Corn in Central Alberta

D. Stanton[1], A.W. Grombacher[2], R. Pinnisch[3], D. Spaner[1]

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Introduction

New corn (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. Agronomic evaluation of new hybrids is needed in this environment to maximize productivity and evaluate potential of this new cropping option. Decreasing row spacing from 30" to narrow 15" row widths may result in increased rate of canopy closure and decreased intra-row competition. This would improve the competitive ability of corn in this region where corn is poorly adapted. Likely, Improved competition for resources during cool spring temperatures will enhance yields and may decrease time to maturity in this season limiting environment

Our objectives are to determine how variety and row spacing affect development, yield, and maturity in this new environment. The data can be used for the development of better adapted hybrids, and for a basis in the design of further agronomic research. Recommendations can also be made to producers to achieve more optimal yields and consistent maturity despite environmental variability in this region.

Materials & Methods

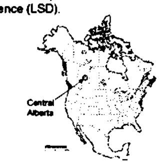
We evaluated five early Pioneer Hi-Bred maize hybrids (39N03, 39F45, 39W54, 39T68, 39M27) ranging from 2000 to 2250 corn heat unit maturity rating. These hybrids are being tested in a factorial experiment at two row widths: 76cm and 38cm at 74 000, plants/Ha in a split plot design with four replicates. Main plots consisted of row spacing with varieties as the sub-plots. In 2002 two locations in central Alberta were evaluated with 2 locations in 2003. Plots are over-seeded mechanically and thinned at V4 stage. Main plots measured 5m x 25m and sub-plots measured 5m by 5m with 6 rows spaced at 76cm or 12 rows spaced at 38cm.

Data was collected for emergence, V3, V6, anthesis, 50% silk emergence. Harvest of the center two rows in 76cm plots or 4 rows in 38cm plots determined yield. A sub-sample of 4 whole plants were randomly selected to determine dry matter percentage. A rendered whole plant sample was then analyzed by NIR for quality parameters.

Presented data is from the 2002 and 2003 field seasons. Data was analyzed by analysis of variance using the General Linear Model in SAS statistical software. A combined analysis of silking date, maturity, and yield indicated no significant interactions between treatments. Mean separation of treatments was obtained by Fisher's Least Significant Difference (LSD).

Maturity Ratings

Hybrid	CRM	CHU
39F45	73	2050
39N03	72	2000
39T68	77	2250
39M27	77	2250
39W54	73	2100



Acknowledgements

This work is supported by NSERC and Pioneer Hi Bred Production LTD.

Results

Days to 50% silking is significantly different between row spacing treatments ($P<0.05$) Significant interactions between hybrid and environment occurred in 2002 due to high drought stress. Combined across environments and years narrow row spacing (38cm) silked 1 day earlier than normal 76cm row spacing. (see table 1)

Maturity level measured by harvest % moisture differed significantly by hybrid ($P < 0.05$), by row spacing ($P < 0.05$) and by environment. There was no significant interaction between environment, hybrid and treatment factors ($P > 0.05$). Dry matter percentage increased by an average of 0.85% in 38cm spacing compared with 76cm spacing (table 2).

Dry matter yield showed a significant row spacing treatment effect ($P<0.0001$). In 2002 narrow row corn showed an average of 1500kg/Ha yield advantage (4.3t/Ha @ 65% moisture). In 2003 the dry matter yield increase was even greater for narrow row corn (38cm) with an average increase yield of 2381kg/Ha (6800kg/Ha @65% moisture). (table 3, table 4)

Silking Date 2002-2003 average

Hybrid	Row Spacing cm	Row Spacing Inches	Julian Date	Days Advantage Narrow Row
39F45	38	15	218.3	-0.71
	76	30	219.0	0
39M27	38	15	224.6	-0.64
	76	30	225.2	0
39N03	38	15	219.6	-1.88
	76	30	221.4	0
39T68	38	15	223.8	-0.89
	76	30	224.7	0
39W54	38	15	225.5	-0.76
	76	30	226.3	0

Table 1. Day to silking response of early hybrids to row spacing.

Dry Matter Percentage 2002-2003 avg

Hybrid	Row Spacing cm	Row Spacing Inches	Dry Matter (%)	% Advantage Narrow Row
39F45	38	15	33.9	0.14
	76	30	33.8	0
39M27	38	15	29.3	-0.13
	76	30	29.4	0
39N03	38	15	35.6	2.56
	76	30	33.0	0
39T68	38	15	30.0	0.50
	76	30	29.5	0
39W54	38	15	28.7	1.13
	76	30	27.6	0

Table 2. Maturity response of hybrids to row spacing.

Dry Matter Yield (tonnes/Ha) 2002 average

Hybrid	Row Spacing cm	Row Spacing Inches	Yield (t/Ha)	% Advantage Narrow Row
39F45	38	15	5.49	111
	76	30	4.94	100
39M27	38	15	4.96	110
	76	30	4.50	100
39N03	38	15	6.50	154
	76	30	4.23	100
39T68	38	15	6.58	153
	76	30	4.30	100
39W54	38	15	6.42	145
	76	30	4.41	100

Table 3. Yield response of hybrids to narrow row spacing in 2002: A high drought stress growing season.

Dry Matter Yield (tonnes/Ha) 2003 average

Hybrid	Row Spacing cm	Row Spacing Inches	Yield (t/Ha)	% Advantage Narrow Row
39F45	38	15	14.16	116
	76	30	12.20	100
39M27	38	15	14.06	118
	76	30	11.89	100
39N03	38	15	14.63	121
	76	30	12.02	100
39T68	38	15	15.29	124
	76	30	12.34	100
39W54	38	15	14.86	118
	76	30	12.62	100

Table 4. Yield response of hybrids to row spacing in 2003: A more typical set of Alberta environments.

Conclusions

- Narrow row spacing treatment of 38cm showed a number of advantages over typical 76cm row spacing
- Earlier silking date of narrow row corn is advantageous in this short season environment. Season limiting grain filling period often results in immature silage harvest despite using earliest available hybrids. Earlier silking increases crop maturity at harvest
- Narrow row spacing showed a slight advantage in crop maturity at harvest. This advantage would be especially important for producers in shorter frost free period areas or that are growing hybrids in the later maturity range of this study.
- Decreasing row spacing did not give enough of a maturity advantage to justify growing higher heat unit hybrids. Narrow row spacing should not be used as an alternative to growing lower heat unit, better adapted varieties
- Yield in narrow row corn showed a distinct and consistent advantage over corn planted at normal 76cm spacing. This yield gain occurred under both typical and drought conditions. Despite higher yields maturity did not decrease, thus narrow row corn has no obvious disadvantages
- Since most growers are new to corn production initial investments should be directed to narrow row planters

Appendix G: Poster presentation "The effects of spatial and temporal agronomics on silage corn in Central Alberta."

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The effects of Spatial and Temporal Agronomics on silage corn in Central Alberta

D. Stanton[1], A.W. Grombacher[2], R. Pinnisch[3], D. Spaner[1]

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Introduction

New corn (*Zea mays L.*) hybrids have been developed for short season environments that are capable of achieving silage maturity in central Alberta. A number of agronomic studies were undertaken to determine performance of four Pioneer Hi-bred corn varieties ranging in maturity. Ultimately, the definition of optimum productivity in silage production is animal performance, specifically pounds of milk or beef per acre of crop. Agronomic decisions made by producers affect the silage quality of the end product. Increasing plant density can result in greater yields, however it also delays maturity. Planting a later maturing hybrid can increase yield but often results in decreased maturity and lower grain to stover ratios than earlier hybrids. Agronomic decisions such as plant date and row spacing will also affect quality.

Our objectives are to determine how outcomes of agronomic studies translate into productivity by examining the quality of silage from these experiments. The data is important in determining how to interpret results of the agronomic experiments.

Materials & Methods

We are evaluating four early Pioneer hybrid maize hybrids (39N03, 39F45, 39W54, 39T68) ranging from 2000 to 2250 corn heat unit maturity rating. These hybrids were tested in three experiments: 1) plant density, 2) sowing date, and 3) row spacing. Experiments were conducted in central Alberta Canada in 2002 and 2003. Plant density experiments tested hybrids at 49 000, 74 000, 99 000 and 124 000 plants/Ha in a complete randomized block design with four replicates, in seven environments. Plant date experiments evaluated hybrids at 4 planting dates spaced 11 days apart starting May 1 with 5 environments total. Row spacing experiments compared hybrids at typical 76cm row width vs narrow 38cm row spacing over 4 environments. All plots were over-seeded mechanically and thinned at V4 stage. Plots measured 5m by 5m with 6 rows spaced at 76cm (12 rows spaced at 38cm in the row spacing experiment).

Harvest of the center two rows determined yield. A sub-sample of 4 whole plants are randomly selected to determine dry matter percentage. A rendered whole plant sample is then analyzed by NIR for quality parameters. Milk yields and milk yield per ton were calculated using the University of Wisconsin Milk2000 spreadsheet version 7.54 (Shaver et al. 2000)

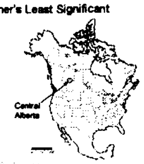
Presented data is from the 2002 and 2003 field seasons. Data is analyzed by analysis of variance using the General Linear model in SAS statistical software. Mean separation of treatments was obtained by Fisher's Least Significant Difference (LSD).

Maturity Ratings

Hybrid	CRM	CHU
39F45	73	2050
39N03	72	2000
39T68	77	2250
39W54	73	2100

POPULATIONS

Plants/acre	Plants/Ha
20000	49000
30000	74000
40000	99000
50000	124000



Acknowledgements

This work is supported by NSERC and Pioneer Hi Bred Production LTD.

Results

Plant density experiments showed significant effects of variety and density on quality parameters with no interactions (P<0.05) Ash, DNDF and milk per acre were not significantly effected by density. Plant Date experiments also showed significant effects of variety and planting date on most quality parameters (P<0.05). Protein and DNDF were not significantly effected by planting date (P>0.05). Row spacing milk per acre showed significant effects of both variety and treatment. NDF, ADF, CP, Starch, Invitro digestibility (% whole plant corn), simple sugars, dry matter, and milk per ton were all significantly effected by variety but not by row spacing.

Table 1. Quality Response to Hybrid and Plant Density Central Alberta 2003

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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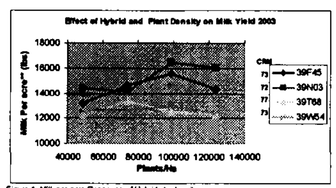

Figure 1. Milk per acre Response of Hybrids to density

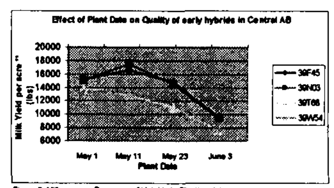

Figure 2. Milk per acre Response of Hybrids to Planting date

Table 2. Quality response to Planting Date and Hybrid in central Alberta

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Table 3. Quality response to Row Spacing and Hybrid in central Alberta

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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Conclusions

- Lower corn heat unit hybrids benefited from higher plant density increasing yield without excessive quality decrease. This resulted in higher calculated milk per acre harvested.
- Earlier hybrids outperformed later hybrids in calculated milk per acre and thus should be preferred for planting in the central Alberta environment.
- Optimum planting date of early hybrids resulted in maximum milk per acre yield. Later hybrids did not achieve the milk per acre yield of early hybrids regardless of planting date
- Narrow row spacing produced more milk per acre by increasing yield as the milk per ton was higher at normal 76cm row spacing.
- Early hybrids outperformed later hybrids in the very short season central Alberta environment

References:

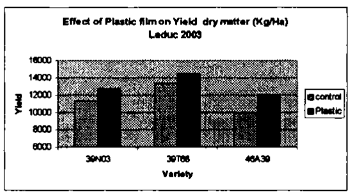
** Indicates values calculated using the MILK2000 spreadsheet. Randy Shaver (2000) University of Wisconsin Milk 2000 Spreadsheet. Version 7.54

Appendix H: Information sheet "The use of clear plastic mulch film for corn production in the very short season of central Alberta"

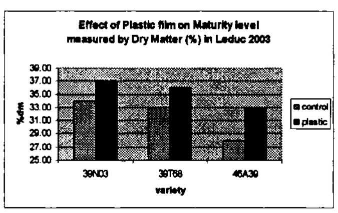
The use of clear plastic mulch film for corn production in the very short season of central Alberta

Introduction

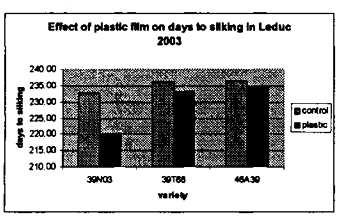
The use of clear plastic mulch film was investigated as a method for increasing the heat units available for seedling growth of corn in the cool temperate climate of central Alberta. A field planter capable of laying down a thin polyethlyene film over two rows of corn was utilized to conduct field trials. In 2002 and 2003 two fields were grown with 3 varieties comparing the use of plastic mulch film to conventionally grown corn.



Plastic mulch films were able to increase the yields for all varieties tested however the price at the time of testing was $150 requiring approximately 3-4 tons of silage per acre to reach the break even point. This was not accomplished by the mulch film treatments.



Maturity level of hybrids tested were improved over conventional corn production in this region. The improvements would not justify use for silage production in this region as they were not accompanied by economically significant yield increases. The use for high value crops such as sweet corn may be an economically viable expense as decreasing time to market may result in increased revenue.



Days to silking showed earlier transition from vegetative to reproductive development. This would allow a crop such as sweet corn to begin cob development earlier allowing earlier marketing or decrease the risk of frost if this system could be improved to allow greater yields for forage production.

Agronomic Improvements: Recommendations from this study for future research:

Planting dates used in this study were May 7th, and May 12th. Planting at this time increases the amount of heat available however it does not increase the season length. The extend system would allow earlier planting and offer protection from frost thus earlier plantings should be done to test improvements in yield from increased season length and heat availability.

Planting dates used in this study exposed the corn to high temperatures within the enclosed environment created by the clear plastic mulch. This lead to burning of leaves and heat stress. Earlier plantings may have alleviated this problem. This may however be a problem in environments with long periods of bright sunlight. If this is the case then the plastic film would need modification to prevent this problem.

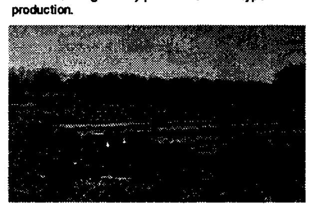
Planting of sweet corn in a separate trial resulted in good emergence of the plastic mulch treatment after May 7th planting compared with conventionally planted sweet corn that showed no emergence. This shows that the extend system could be used to allow earlier plantings of sweet corn improving plant stands and time to market.

Plastic film used was photo-degraded however the amount of time the film took to degrade did not correspond to the time that it took plants to outgrow the furrow created by the planter. Difficulty in emerging from the plastic resulted in injury and leaf loss. Starch based films were available and may offer improvements. Earlier planting may have decreased this problem as well. In both years of study plastic had to be removed by hand however injury occurred prior to removal.

Plastic film that is starch based would likely have improved breakdown characteristics compared to the photo-degraded polymer tested. The polymer that was buried to hold the film down did not degrade and created problems with fall tillage.

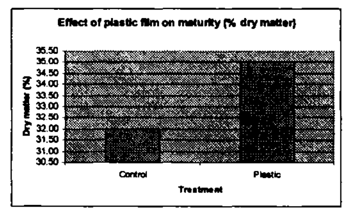
Film did not stay in position in many cases and was subject to damage from field debris such as stubble. Thus modification to the film to make it more resilient and to improve holding in place is necessary.

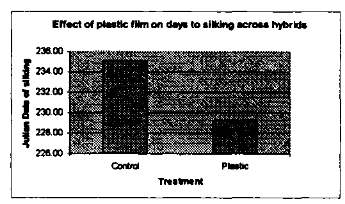
Input cost of the film is prohibitive for use in silage corn production. Use in high value crops such as sweet corn may be viable however in Canada where land is more abundant than labor increased labor and costs are generally prohibitive to this type of production.



Plastic mulch film may be a viable option for high value vegetable crops in Alberta

Plastic is subject to damage negating some of the benefits





Conclusion:

Plastic mulch film has displayed some merits in this environment but is not a viable option for increasing corn silage yields. Further testing could show increased benefits. Testing for high value crop production such as vegetables could prove cost effective in this environment

Plastic mulch film increased the temperature increasing the rate of growth however excessive heating resulted in some damage to plants.