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RESPONSE OF LEAFY REDUCED-STATURE MAIZE (*Zea mays* L.) HYBRIDS TO PLANT POPULATION DENSITIES AND PLANTING PATTERNS IN A SHORT-SEASON AREA.

Sultan Hussein Begna
Department of Plant Science
McGill University, Montreal
Canada

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Short Title:

Leafy reduced-stature maize - plant density and spacing

Thesis format description

This thesis is a collection of papers which will be submitted for journal publications. It includes an abstract, a general literature review, literature cited, hypotheses and objectives, three potential papers, a general discussion, acceptance or rejection of hypotheses, conclusions and suggestion for future research. Each of the manuscript chapters consists of a preface, and the names of contributing authors, an abstract, an introduction, materials and methods, results and discussion, and literature cited. The format of the manuscripts has been changed to be consistent within this thesis, according to guidelines set by the Faculty of Graduate Studies and Research.

ABSTRACT

MSc. Sultan Hussein Plant Science

RESPONSE OF LEAFY REDUCED-STATURE MAIZE HYBRIDS TO PLANT POPULATION DENSITIES AND PLANTING PATTERNS IN A SHORT-SEASON AREA.

The yield of short-season hybrids is lower than long-season hybrids, mainly as a result of the low final leaf area developed by the short-season plants. This is due to the smaller plant stature and smaller leaf number and size of short-season adapted hybrids. In addition, in short-season areas the thermal-time available may be insufficient to mature grain of current maize hybrids. Maize hybrids which accumulate leaf area quickly, mature earlier, yield well and tolerate higher population densities better than the currently available hybrids would be more suitable for production in short-season areas. The "Leafy reduced-stature" maize hybrids, which have only recently been developed, have traits which address these criteria. There has been no previous effort to evaluate the effects of more than two plant population densities or the effects of planting patterns on the yield, yield components and vegetative growth of these hybrids. In 1995, field experiments were conducted at two sites near Montreal to compare the response of leafy reduced-stature (LRS), non-leafy normal stature (NLNS), and non-leafy reduced-stature (NLRS) maize hybrids to plant population densities and planting patterns. LRS maize hybrids showed the most rapid growth of the first ear, and the highest yield per single plant and per hectare at high plant population densities in paired rows. LRS hybrids also had longer grain filling periods, lower grain moisture contents and higher harvest indices than conventional (NLNS) hybrids. Rapid growth of the first ear and a higher harvest index are indications that LRS hybrids should be more tolerant of higher population densities than currently available hybrids. Therefore, LRS hybrids show promise for production in short-season areas at high plant population densities where maize cultivation is not currently economical due to shortness of the growing-season.

RÉSUMÉ

La réponse des hybrides de maïs feuillus à stature réduite à la densité de la population et le patron de semis dans une zone à saison courte

Le rendement des hybrides de maïs de saison courte est plus faible que celui des hybrides de saison longue surtout à cause de la faible surface foliaire développée par les premiers en fin de saison. Ceci est du à la stature réduite et au faible nombre et à la petite taille des feuilles de ces hybrides. En plus, dans les zones de courte saison, les unités thermiques sont insuffisantes pour la maturation des graines des hybrides courants. Des hybrides de maïs qui accumuleraient une surface foliaire rapidement, qui auraient une maturité hâtive et un bon rendement et tolèreraient mieux une forte densité de population que les hybrides courants, seraient mieux adaptés à la production en courte saison. Les hybrides feuillus à stature réduite (FSR) qui viennent d`être developpes possèdent des traits qui peuvent résoudre ces problèmes. Cependant, il n'y a pas encore eu d'évaluation de l'effet de la densité de population et du patron du semis de ces hybrides FSR sur le rendement et ses composantes. Deux expériences ont été faites en 1995 sur deux sites à Montréal pour comparer la réponse à la densité de population et au patron de semis du maïs FSR, du maïs non feuillu à stature réduite (NFSR) et du maïs non feuillu à stature normale (NFSN). Les hybrides FSR avaient la croissance la plus rapide du premier épi, le plus fort rendement par plante et par hectare à forte densité de population dans des rangs jumelés. Les hybrides FSR avaient une plus longue période de remplissage des grains, un taux d'humidité plus faible et des indices de récoltes plus élevés que ceux des hybrides NFSN. La croissance rapide du premier épi et les indices de récolte élevés indiquent que les hybrides FSR seraient plus tolérants envers les fortes densités de population que les hybrides NFSN. Ceci veut dire que la production de ces hybrides à fortes densités de population dans les zones à saison courte où la production du maïs n'est pas économique est prometteuse.

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CONTRIBUTIONS OF CO-AUTHORS

The contents of Chapter 3 to 5 are derived from manuscripts intended for publication, and which will be co-authored by myself and my supervisor, Professor D.L. Smith and three members of my committee, Drs R.I. Hamilton, L.M. Dwyer, and D.W. Stewart from Agriculture and Agri-Food Canada. Professor Smith provided the necessary funds and assistance for this research, including the normal supervisory guidance and the reviewing of manuscripts before their submission for publication. The various committee members provided guidance beyond that of a normal committee, both in terms of reviewing the manuscripts and giving valuable suggestions. Dr. R.I. Hamilton developed and provided all the genetic materials needed for the research.

Chapter 1

LITERATURE REVIEW

INTRODUCTION

Cereals are crops grown primarily for their edible starchy seeds. They constitute the world's major sources of food for humans and feed for livestock. It has been estimated that cereal grains provide 56% of the food energy and 50% of the protein consumed on earth (Christie, 1987)

1.1 World maize production levels

On a world wide basis the major cereals, in descending order of importance, are wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), maize (*Zea mays* L.), barley (*Hordeum vulgare* L.), and sorghum (*Sorghum bicolor* L.). Wheat, rice, and maize together make up 3/4 of the world grain production. Maize is a major crop for both direct and indirect human consumption as it forms a major crop energy feed for animals. For some cultures, maize has been portrayed as the staff of life. In Mexico, close to 98% of the maize crop is consumed in the form of tortillas, the daily bread of the Mexican people (Wellhausen, 1976).

Although pre-eminently an American crop, maize is one of the most widely distributed of the world's food plants. It is grown from 55° N latitude in Canada and the former USSR to 40° S latitude in South America. It thrives almost equally well in the short summer of Canada and the perpetual summer of tropical Columbia. A crop of maize matures somewhere in the world in every month of the year. From the standpoint of area planted, maize ranks second among the world's most extensively produced crop plants, being exceeded only by wheat (Cocker, 1972)

In the developing world, maize ranks third in importance, after rice and wheat. In total, there are over 80 million ha planted with maize in developing countries. This represents 60% of the world's maize area, though only 40% of global production is harvested from Third World maize lands (FAO, 1990).

Maize has been grown in Canada for many years. The largest production area is Ontario and Quebec, where the crop are grown extensively for grain and fodder. In other parts of the country, principally Manitoba and the Maritime provinces, maize is grown successfully for fodder, but with a more limited success for grain. Maize production area in Canada increased from 68,000 in 1934-1938 to 1.2 million hectares in 1994. The yield has increased from 2.5 t ha^{-1} in the 1930's to 6.8 t ha^{-1} in 1994. There are around 305,000 ha of maize produced each year in Quebec; only 25,000 ha are fodder. In Ontario there are 821,500 ha of maize of which 121,400 ha are used for fodder (Statistics Canada, 1995). Maize is the most widely produced crop in Quebec. In Ontario and Quebec average grain yields were 7.1 and 6.3 t ha^{-1}, respectively in 1994 (Statistique Agricoles, 1994). The expansion of maize production occurred mainly in Ontario, Quebec and the Red River Valley of Manitoba, largely through the greater popularity which the crop has achieved since the introduction of hybrid maize, the introduction of mechanical harvesters, which enabled the grower to harvest more hectares with less labour, and the extension of maize production into new areas, made possible by the availability of improved early-maturity hybrids. Maize is grown for grain in many areas formerly regarded as unsuited for its production (Berger, 1962). Yield of grain maize varies considerably from year to year as a result of seasonal conditions.

1.2 Range of adaptation

The maize crop has a wide adaptation and is able to grow in regions ranging from the semiarid, with an annual rainfall of 20 to 25 cm, to those where annual rainfall may exceed 400 cm. Because of the wide range of climatic conditions over which maize is grown, precise limiting conditions for maize production cannot be set. The bulk of the maize is produced between latitudes 30 °S and 55 °N with relatively little grown at latitudes higher than 47°N any where in the world (Benson and Pearce, 1987). According to the 1990 production figures (FAO, 1990), 43% of the world's total maize production was grown in North America and 3 % in the former USSR.

1.3 Physiological and morphological characterization of maize

The yield of any crop represents the summation of numerous physiological processes and overall morphological development. Normally maize plant development is divided into the vegetative and reproductive stages. The vegetative stage can be further divided into stages like planting to germination, germination to emergence, and emergence to tassel initiation, whereas the reproductive stage is divided into tassel emergence to silk emergence, silking (silk emergence) to the onset of grain filling and grain filling to maturity. The effect of temperature on development varies from stage to stage. Therefore it is important to partition the limited heat units available for each stage in order to determine the effects of thermal time on maize yield in a short-season environment.

Vegetative phase duration and leaf area index (i.e. source size) are positively correlated (Muldoon et al., 1984). The ability of a maize crop to generate photosynthate is dependant on leaf area per plant, leaf angle and plant density. Leaf area per plant is often determined by leaf number and size, which are in turn influenced by environmental factors such as temperature and photoperiod (Warrington and Kanemasu, 1983a,b). Genotype affects leaf number and size in maize. Increasing the vegetative phase of the plant leads to delayed flowering and increases in leaf number. Plant height and total leaf number are positively correlated with flowering-time in maize (Cross and Zuber, 1973).

Heat sums (eg. corn heat units) are one approach used for defining developmental responses to temperature. The use of heat-sum methods for determining the response of flowering time and grain maturity to temperature in maize have been examined extensively (Gilmore and Rogers, 1958; Cross and Zuber, 1973; Mederski et al, 1973; Coelho and Dale, 1980). Heat-sum or thermal-unit methods are now widely used for maturity classification of commercial maize hybrids for particular geographical locations. In particular, they are used for predicting the ontogeny of maize, especially the timing of flowering and harvest maturity. The actual number of days required for maize to reach maturity varies widely with changes in the environment, although cultivars are often designated as having a certain number of days to reach maturity. Different approaches have been used for maize. Brown (1969) developed equations that were used to determine maturity ratings for maize in Ontario, Canada. Leaf number also serves as an indicator of maize maturity, whereby early maturity maize genotypes have fewer leaves than late maturity genotypes (Chase and Nanda, 1967; Allen et al., 1973). The contribution of upper leaves and lower leaves to the grain is very different; more contribution is made by the upper leaves than those below the ear (Alison and Watson, 1966). Eastin (1969) reported that almost all the photosynthate produced in the upper leaves goes to the grain. Therefor an increase in leaf number or size in the upper part of the plant can increase the grain yield of maize (Johnson, 1973). By manipulating photoperiod, Hunter (1980) was able to increase the leaf area per plant and the yield of a short-season maize hybrid. He suggested that the yield was increased by a greater assimilate supply from a larger leaf area. This yield increase was also due to a 4-5 day increase in the grain-filling period for plants grown under long photoperiod. A longer vegetative period before flowering increases source size (Giesbrecht, 1960, Beil, 1975; Troyer and Larkins; 1985), while a longer grain filling period after flowering increases sink size in both Corn- Belt and short-season material (Daynard, 1969; Daynard and Kannenberg, 1976; Corke and Kannenberg, 1989; Troyer, 1990; Dwyer et al., 1994). Hunter (1980) suggested that breeders should select genotypes with rapid leaf area expansion during the pre-silking stage. Grain sink size is strongly associated with kernel number in grain crops, and kernel number is a function of plant dry matter accumulation (Fischer, 1985).

Tasselling and silking time are very weather dependant. Wallace and Bressman (1973) reported that a 115-day cultivar took 74 days from planting to tasselling when the average temperature was 20 ^{0}C, but only 54 days when the temperature was approximately 23 ^{0}C. High temperatures, for example 35 ^{0}C, generally cause stress and they are usually combined with moisture stress.

If too many kernels are aborted total sink size may limit yield (Yoshida, 1972). Prine (1971) also found that a poor light environment at very high plant populations could cause ear barrenness. Barnes and Wolley (1969) subjected a "stress-sensitive" single-eared hybrid and a "stress resistant" two-eared hybrid to severe moisture stress. At the silking and pollination stages the two-eared hybrid was more tolerant of stress, with a yield reduction of 14%, compared with a 73% reduction for the single-ear hybrid.

The successive stages of seed development are accompanied by reductions in seed moisture, development of a black layer in the placental-chalazal region of the milky endosperm beginning at the seeds' apex and ending at the base (Aldrich, 1943; Daynard and Duncan, 1969).

Harvesting time of maize depends not only on environmental conditions in the fall but also on proper hybrid selection and planting dates in the spring (Duncan and Thompson, 1962). Harvesting earlier at lower grain moisture results in reduced grain drying costs and lower field losses (Olson and Sander, 1988). While most maize hybrids mature when the grain is at about 30% moisture, the ideal moisture content to start combining is considered to be about 25% (Olson and Sander, 1988).

1.4 Limitations of short growing season areas for maize production

The main problems of maize production in short season areas are the lower leaf area index of the plants and insufficient corn heat units during the growing season. Maize hybrids grown in short-season areas tend to have low final LAIs, mainly due to shorter plant stature, which results in the production of fewer and smaller leaves than hybrids grown in longer season areas (Chase and Nanda, 1967; Hunter et al., 1974). Hunter (1980) reported that the maximum LAIs of maize in short-season areas with normal plant population densities are low, with values not more than 2.7. At these LAIs, a maize canopy can intercept only about 75% of full sunlight. Normally early-maturing maize hybrids are source-limited (limited in assimilate supply to the grain) (Hunter, 1980; Cross, 1991), whereas mid-western hybrids are sink limited (shortage of sink to accommodate assimilate) (Tollenaar, 1977; Hunter, 1980).

The second problem for maize production in a short season area is that daily or seasonal thermal (corn) heat units are insufficient for the complete grain filling period of the current hybrids, and this in turn, becomes critical to yield. Short-season maize growing areas have longer and cooler days at flowering, resulting in both thermal and photoperiod responses which slow maturation at harvest. The problem in very short-season areas is that the seasonal thermal time available may be insufficient to mature the grain of current maize hybrids. Troyer (1990) reported that maize production in short-season areas is normally limited by heat units and by the frost free period; current hybrids seldom finish grain filling prior to the first killing frost. Thus earlier flowering maize hybrids have smaller plant size and longer grain filling periods, while later flowering hybrids have larger plants size and shorter grain filling periods.

There are two ways of increasing the leaf area of early maturity maize hybrids without delaying the silking time: breeding for increased leaf area per plant and increasing the plant population density. Crosses between Leafy-normal and non-leafy reduced-stature inbreds may result in hybrids with more rapid early leaf area development. The leafy and reduced-stature traits have potential for use in further studies and may allow the expansion of maize production into areas where maize production was previously regarded as not economical.

1.5 The Leafy and reduced-stature traits

Plants bearing the leafy (Lfy1) gene are characterised by extra leaves above the ear, lower ear placement, highly lignified stalks and other plant parts, early maturity and higher yield potential than otherwise equivalent genotypes of maize (Shaver, 1983). The leafy trait confers an increase in leaf number relative to normal hybrids. Leafy-types produce a few more leaves below the ear and almost double the number of leaves above the ear; that is a normal hybrid will have four or five leaves above the ear, while a leafy hybrid may have eight or nine (Dwyer, unpublished). The net result of this is that Leafy plants show a dramatic increase in the production of leaf area by the time of maturity (Shaver, 1983). Thus, the Leafy morphology increase in LAI and should confer an advantage through increased light interception and photosynthesis, particularly during the grain filling period (Tollenaar and Dwyer, 1990). The considerable potential for yield increases in Leafy maize is very explainable because the action of the Lfy1 gene can easily double leaf area production (Shaver, 1983). This results in a large increase in available photosynthate, with the bulk of this photosynthate being deposited in the ear (Eastin, 1969). Borojevic and Williams (1982) reported that excessive leaf area indices may have a negative effect on yield; leaf area duration should be harmonized with the length of the vegetative period and the environment in order to preclude negative effects on grain development.

The leafy trait also increases prolificacy. The limited commercial use of prolific maize hybrids has been attributed to poor stalk quality and plant standability (Motto and Moll, 1983; Lonnquist, 1967). Expression of more than one ear per plant may increase competition between the developing ears and the stalk for photosynthate, causing greater reallocation of stalk carbohydrate to the grain sink. Prolific maize has greater yield stability than the non-prolific type resulting from the capacity to alter the number of ears per plant in response to changes in plant population density or environmental conditions (Collins et al., 1965; Hanway and Russell, 1969; Prior and Russell, 1975; Brotslaw et al., 1988). The Lfy1 gene allows as many as three ears per plant with no hint of otherwise poor plant morphology (Shaver, 1983).

Reduced-stature lines are short-statured with good stalk strength (Daynard and Tollenaar, 1983). These are particularly important factors in short-season environments Preliminary results suggest they may also have the ability to increase harvest index (Dwyer, unpublished). The benefits from the reduced-stature trait also include reduced lodging due to insect and wind damage and greater tolerance of higher plant population densities, which can allow further increase in leaf area index for better light interception and weed competition.

Several leafy by reduced-stature crosses have been evaluated along with non-leafy reduced-stature, Leafy normal and non-leafy normal hybrids for their agronomic and physiological aspects in a short-season areas in eastern of Canada (Modarres, 1995). Modarres (1995) found that Leafy reduced-stature hybrids produced more leaf area above the ear and more yield than the non-leafy reduced-stature and early conventional maize hybrids, particularly at high plant population density.

1.6 Effects of plant population density and planting patterns on maize

1.6.1 Plant population density effects on maize

In effective crop production, efficient utilization of available light is considered as an important factor and is strongly affected by crop canopy structure (Daughtry et al., 1983). Photosynthetic efficiency and growth are often related to canopy architecture, which strongly affects the vertical distribution of light within the maize canopy (Williams et al., 1968). Canopy light interception and photosynthesis are closely related to leaf area index and crop yield (Pearce et al., 1965). Maize yields have been increased by increasing light interception through early planting (Pendleton and Egli, 1969), tassel removal, reflective surfaces placed between the rows (Schoper et al., 1982), and use of artificial lighting (Graham et al., 1972).

Based on many years of agronomic research, including crop simulation modelling and remote sensing applications, it is clear that it is important to be able to predict leaf area development, crop canopy photosynthesis, evapotranspiration, dry matter production and final yields. These are all influenced by incident solar radiation and its interception by leaf surface area, which can be calculated once the leaf area development per plant is defined (Warington et al., 1983ab).

Grain yield of maize has a positive functional relationship with leaf area index until an optimum LAI, which is dependent on the plant canopy architecture, is achieved (Williams et al., 1968). Eastin (1969) suggested that optimum arrangements of leaf area exist for given genotypes, plant population densities, and row spacings, and that the optimum will change in response to any one of these factors.

Increasing plant population densities has been investigated by many plant researchers as a way of improving interception of incoming solar radiation by maize canopies (Duncan et al., 1967; Loomis et al., 1967; Winter and Ohlrogge, 1973; Pepper, 1974; Daughtry et. al., 1983). Leaf area index concentration and the light capturing capability of the plant canopy, particularly at the ear level, are important parts of the plant canopy in the source-sink relationship and important considerations for short-season maize genotypes for which plant population density can be an important tool for increasing total source potential.

Plant scientists have long speculated about plant densities and researched plant competition to find the optimum plant densities for crops including maize. However there is no single rule for all conditions because the optimum density is dependant on all unmanageable environmental factors and manageable factors such as soil fertility, maize hybrid selection, seeding date, planting pattern, and harvest time (Nunez and Kamprath, 1969; Brown et al., 1970; Rhoads, 1970; Lutz et al., 1971; Duncan; 1972; Stanley and Rhoads, 1975; Tetio-kagho and Gardner, 1988b). The optimum plant density may not be the same for all hybrids within a maturity group. For example taller, leafier genotypes with bigger ears may have an optimum plant density that is lower than shorter smaller-eared genotypes (Carmer and Jacobs, 1965, Warren, 1963). Maize hybrids used in the temperate regions generally have higher optimum planting densities.

It is also well known that the grain yield of a single maize plant is reduced by the nearness of its neighbours (Duncan, 1984). Single plant yield reduction is mainly due to the effects of interplant competition for light, water, nutrition and other environmental factors. Grain yield per unit area (Stinson and Moss, 1960; Early et al., 1966; Prior and Russell, 1975; Karlen and Camp, 1985; Tetio-kagho and Gardner, 1988b) and plant height (Major and Daynard, 1972) increase to a maximum and then start decreasing with increasing plant population density. The response of grain yield per unit area to increasing plant density is parabolic (Karlen and Camp, 1985).

Ear weight, diameter and length, and kernel number per ear were increased, but total yield was decreased by reducing plant population density (Baenziger and Glover, 1980). Stringfield and Thatcher (1947) found that kernel row number per ear in a range of hybrids did not change when plant population density was increased from 16,000 to 46,000 plants ha^{-1}. Number of plants at very low or very high population densities becomes a limiting factor for the yield of maize crops. At low population densities yield is limited by the number of plants whereas at high population densities yield is limited by the number of barren plants (Buren et al., 1974; Daynard and

Muldoon, 1983), a decrease in number of kernels per ear (Tetio-Kagho and Gardner, 1988b) or both (Hashemi-Dezfouli and Herbert, 1992). Reductions in grain yield at higher population densities may have resulted from fewer flower initials being formed prior to flowering, poor pollination resulting from asynchrony of tasselling and silking, or from abortion of kernels after fertilization (Daynard and Muldoon 1983; Karlen and Camp 1985; Heshemi-Dezfouli and Herbert, 1992).

Maize hybrids used in temperate regions generally have optimum planting densities close to 7.0 plants m^{-2} (Russell, 1985; Tollenaar, 1991). It is important to select hybrids that are tolerant of high plant densities. Buren et al. (1974) reported that density tolerant maize hybrids are generally of early maturity, smaller in size, characterized by rapid completion of the first ear and first appearance of ear silk, prolificacy, smaller tassel size, and greater efficiency in the production of grain per unit leaf area. The semi-reduced-stature, compact (ctl) and reduced-stature (rd1) mutants in inbred backgrounds have been shown to be more resistant to population stress than non compact and normal-stature inbred lines (Nelson and Ohlrogge, 1957).

Several researchers have reported that a higher harvest index is not always strongly related to dry matter production (Vattikonda and Hunter, 1983; Allen et al., 1991; Cox et al., 1994). This is also highly dependant on uncontrollable environmental factors and other controllable factors (Deloughery and Crookston, 1979). Tollenaar (1989) reported that recent hybrids maintain a constant harvest index as plant density increases because they are less prone to plant bareness at high densities than older hybrids.

Height reductions can occur through a shortening of each internode. As a result of changed partitioning within the shoot, the assimilates saved by stem reductions are translocated to ear development, resulting most frequently in increased grain setting (Evans, 1984). Brooking and Kirby (1981) and Thorne (1982) reported that several short stalked varieties develop heavier ears at anthesis than do comparable tall varieties. A decrease in the height of a plant can lead to increased harvest index (Johnson et al., 1986; Edmeades and Lafitte, 1993). This is the major reason for breeding to reduce vegetative parts to their optimum size and produce short plants (Borojevic, 1990). Borojevic (1990) also reported that reductions in height caused higher harvest indices, more resistance to lodging and, when planted at higher plant population densities, more nutrient uptake, resulting in higher yields per unit area.

Corn heat units from planting to tasselling and to silking and days between tasselling and silking are often changed by plant population density. Days between tasselling and silking increased (Hashemi-dezfouli and Herbert, 1992). Pollen-shed to silking time is an important indicator of density stress in maize (Edmeades et al., 1993). Genotypes that are tolerant of high density stress usually display a shorter interval between 50% pollen shed and 50% silk emergence than intolerant genotypes under high plant population densities (Mock and Pearce, 1975).

1.6.2 Effects of planting pattern on maize

The spacing of maize rows greatly affects plant distribution within the row for any given plant density. Plants compete with each other for nutrients, light and other growth factors. Therefore, it is reasonable that plants spaced an equal distance from each other would provide for minimum competition and maximum yield at any given plant density (Olson et al., 1988). Radiation interception by a crop is thought to limit productivity when other environmental factors are favourable (Blackman and Black, 1959; Loomis and Williams, 1963; Monteith, 1981; Ottman and Welch, 1989). In a plant canopy usually upper leaves are radiation saturated or less efficient and lower leaves have reduced photosynthesis, mainly because of shading. Therefore a more uniform distribution of solar radiation can be advantageous as upper leaves become less light saturated and lower leaves less radiation starved. Partial redistribution of radiation from the upper to lower leaves can be beneficial because the plant leaf is more efficient at lower irradiance (Loomis and Williams, 1969). Planting pattern has an influence on the distribution of radiation in the canopy and the total amount of incident radiation intercepted by a crop (Ottman and Welch, 1989). Plants seeded in narrow rows also intercept more total radiation than in wider rows. Yao and Shaw (1964) found that 0.53 m rows intercepted approximately 7% more light than 1.07 m rows at a plant population of 75,000 plants ha^{-1}. Maize planted in 0.51 m rows intercepted approximately 11% more light than those in 1.05 m rows at a plant population of 80,000 plants ha^{-1} (Scarsbrook and Doss, 1973b).

Reducing row spacing from approximately 1.0 to 0.5 m has resulted in effects ranging from no changes in yield (Giesbrecht, 1969) to increases of as much as 22% (Stanley and Rhoads, 1971; Ottman and Welch, 1989). The yield advantage of narrow rows tends to be realised where water is sufficient (Stickler, 1964; Fulton, 1970) and plant populations are high. Denmead et al. (1962) calculated that a decrease in row spacing from 100 to 60 cm would increase light energy available for photosynthesis by 15 to 20%, thus providing, theoretically at least, an increased yield potential for more equidistant plantings. In fact there are other interactions of row spacing with management practices that affect results. Griffith (1965) reported a 6% increase from row width reduction for an early hybrid but no effect with a full-season hybrid. Brown et al. (1970) also reported hybrid differences in response to row spacing. Reducing row width favours small, less leafy hybrids because these hybrids can benefit more than large leaf hybrids from increased energy available per unit leaf area in more equidistant plantings. Early hybrids tend to be smaller than late hybrids making the early hybrids more suitable for planting in reduced row widths. Early planting as opposed to late planting, also causes a corresponding plant size reduction that favours reduced row spacing. As one would expect, reduced row spacing is most beneficial at high plant population densities (Brown et al., 1970).

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Chapter 2

2.1 Hypotheses and objectives

2.1.1 Hypotheses

The following hypotheses were tested in the work reported in this thesis.

1. The optimum plant population density for a leafy reduced-stature (LRS) maize hybrid is higher than conventional hybrids.
2. Leafy reduced-stature hybrids are more tolerant of higher plant population densities, particularly those above the optimum level, for grain production, than conventional hybrids.
3. Leafy reduced-stature hybrids respond more (have greater yield increases) to narrower rows than do conventional hybrids.
4. Leafy reduced-stature hybrids have the potential to yield more than non-leafy reduced-stature (NLRS) and conventional hybrids at higher plant population densities, and in paired rows.

2.1.2 Objectives

The general objectives of this study were:

1. To study the responses of the best selected Leafy reduced-stature maize hybrids to plant population densities and planting patterns along with one non-leafy reduced-stature and two conventional hybrids, with an emphasis on yield and yield components.
2. To study the responses of the best selected Leafy reduced-stature hybrids to four population densities along with one non-leafy reduced-stature and two conventional hybrids for maize yield, yield components and vegetative growth and based on this data to determine the optimum plant population density of the selected leafy reduced-stature hybrids.

Preface of Chapter 3

An experiment was carried out to evaluate the effects of two plant densities and two planting patterns on Leafy reduced-stature maize hybrids along with non-leafy reduced-stature and conventional hybrids on yield and yield components, and to assess the yield potential of Leafy reduced-stature hybrids at a high plant density in paired rows for short-season areas. The manuscript has been submitted to the Journal of Agronomy and Crop Science and has been co-authored by myself, R.I. Hamilton, L.M. Dwyer, D.W. Stewart, and D.L. Smith.

EFFECTS OF POPULATION DENSITY AND PLANTING PATTERN ON THE YIELD AND YIELD COMPONENTS OF LEAFY REDUCED-STATURE MAIZE IN A SHORT-SEASON AREA.

ABSTRACT

Maize hybrids that yield well, mature earlier with low grain moisture contents, tolerate higher population densities and take advantage of narrow row spacings better than currently available hybrids would be more suitable for production in short-season areas. Leafy reduced-stature maize hybrids, which have only recently been developed, have traits which address these criteria. The objective of this study was to evaluate the effects of different population densities (65,000 and 130,000 plants ha^{-1}) and planting patterns (single rows 76 cm apart and paired rows with 20 cm between rows within a pair and 56 cm between rows of adjacent pairs) on the yield and yield components of two Leafy reduced-stature hybrids (LRS1 and LRS2), one non-leafy reduced-stature (NLRS) hybrid, and two conventional maize hybrids (Pioneer 3979, <2500 CHU; and Pioneer 3902, 2600-2700 CHU) at two sites. All hybrids had higher kernel numbers per row, and single-plant grain yields at the lower population densities when in paired rows, however as plant density increased these variables decreased more in the conventional hybrids than the LRS and NLRS hybrids, which demonstrates the greater tolerance of the reduced-stature hybrids to the stresses associated with higher plant densities. Grain yield was higher for the two LRS hybrids and the NLRS hybrid at 130,000 plants ha^{-1} than at 65,000 plants ha^{-1}. Grain yield of conventional hybrids was reduced at the higher population density. The LRS hybrids matured before both conventional hybrids and outyielded Pioneer 3979 at the higher plant population density in both row spacings at both sites. Harvest index was not affected by population density and this value was not different among the NLRS and conventional hybrids. However, the harvest index of the LRS hybrids was greater than the others. LRS and NLRS hybrids had lower moisture contents and earlier maturities than conventional hybrids. Rapid growth of the first ear and higher harvest index values are indications that LRS hybrids are more tolerant of higher population densities than the conventional hybrids.

Key words: Population density and row spacing, Leafy reduced-stature, grain yield, and grain moisture.

INTRODUCTION

The yield of short-season maize (*Zea mays* L.)hybrids is lower than that of full-season hybrids, mainly as a result of the low final leaf area developed by the short-season plants. This is due to smaller plant stature and reduced leaf number and size for hybrids adapted to short-season areas (Chase and Nanda,1967; Hunter et al.,1974). By manipulating photoperiod, Hunter (1980) was able to increase leaf area per plant and grain yields of short-season maize. Stringfield (1956) found that increasing plant population to maximum levels had a greater effect on the yield of earlier maturing than later maturing hybrids. It seems reasonable that optimum use of the limited growing period for maize is essential for maximizing grain yield development in short-season areas.

One way to increase leaf area index is to increase planting density (Oslon and Sander, 1988). Alessi and Power (1975) studied early maturing maize hybrids in the northern regions of the great plains and found that increasing plant densities up to 74,000 plants ha^{-1} produced LAIs as high as 4.9, although this was dependent on hybrid and season. While single-plant yield decreases with increased plant density, total light interception by the canopy is increased. The response of grain yield per unit area to increased plant density is parabolic (Karlen and Camp, 1985). A decrease in grain yield at superoptimal plant densities is partly due to increased ear barrenness (Buren et al., 1974; Daynard and Muldoon, 1983), decreased numbers of kernels per ear (Iremiren and Milbourn, 1980; Tetio-Kagho and Gardner, 1988), or both. Dungan et al. (1958) found that maize ear weight per plant decreased linearly as plant population increased, as long as yield per hectare increased. Prine and Schorder (1964) suggested the main factor causing the decrease in ear number and yield per plant was the mutual shading of plants. Pendleton and Hammond (1969) found that the relative photosynthetic potential of the maize leaves in the top one-third of the canopy was twice as high as the middle leaves and five times as high as leaves in the bottom third. The optimum planting density for a hybrid is dependant on environmental factors and other controllable factors such as soil fertility, hybrid selection, date of planting, planting pattern and harvest time (Dungan et al., 1958). Grain yield of a single plant is decreased by the nearness of its neighbours (Duncan, 1984) mainly because of higher interplant competition, for light, water and soil nutrients.

The distribution of solar radiation in the plant canopy and the amount of radiation intercepted by the plant is strongly influenced by planting patterns (Ottman et al., 1989). Decreasing row spacing from approximately 1.0 to 0.5 m resulted in effects ranging from no yield increase (Giesbrecht, 1969) to increases as great as 22% (Stanley and Rhoads, 1971). The yield advantage of narrow rows is most likely to be manifested in areas where water is sufficient (Stickler, 1964; Fulton, 1970) and plant populations are high (Hoff et al. 1960). Net solar radiation measured at ground level under narrow-row maize canopies was reported to be 4 to 5% less than maize grown in wider rows indicating a greater interception of solar radiation by the narrow-row canopies. Plants grown at a given plant population density usually yield more grain per unit land area when the distance between adjacent rows is decreased and the distance between plants within a row is increased (Prine, 1969)

Selecting an appropriate plant density and planting pattern is important in the establishment of crop production systems and many investigations have dealt with crop responses to population density. Density-yield studies are very useful for evaluating the reaction of plants to their neighbours (Jolliffe, 1988). Under weed-free conditions, maize yield increases with an increase in plant density, until an optimum plant density is reached (Duncan, 1954; Tollenaar, 1991).

The optimum plant density may not be the same for all hybrids within a maturity group, for example taller, leafier genotypes with bigger ears may have optimum plant densities that are lower than shorter smaller-eared genotypes (Carmer and Jacobs, 1965; Warren, 1963). Maize hybrids used in temperate regions generally have optimum planting densities close to 7.0 plants m^{-2} (Russell, 1985; Tollenaar, 1991).

It is also very important to select hybrids that are tolerant of high plant densities. Buren et al. (1974) reported that density tolerant maize hybrids are characterized by rapid completion of silk extrusion, growth of the first ear and first appearance of ear silk, prolificacy, smaller tassel size, and greater efficiency in the production of grain per unit leaf area. The semi-reduced-stature, compact (ctl) and reduced-stature (rd1) mutants have been shown in inbred backgrounds, to be more resistant to population stress than noncompact and normal stature inbred lines (Nelson and Ohlrogge, 1957).

Plants bearing the Leafy (Lfy1) and reduced-stature (rd1) gene were brought together to produce Leafy reduced-stature hybrids. Modarres (1995) showed that Leafy-reduced stature (LRS) hybrids had the potential to yield well and, that they yield better at 130,000 plants ha^{-1} and narrow spacing (38 cm between rows) than at 65,000 plants ha^{-1} in the same row spacing. However, there has been no previous effort at determining the effects of population density and planting patterns on two commercial quality Leafy reduced-stature hybrids together, or comparing the effects of population density and planting patterns on yield and yield components of LRS hybrids and conventional hybrids.

Based on the above literature it can be hypothesized that maize hybrids which produce more leaf area than current hybrids and develop both leaf area and mature grain more rapidly than current hybrids would be more suitable to short season areas and that manipulation of planting pattern accompanied by increased plant populations would further increase this potential. While narrow rows seem desirable they may be a problem for maize producers wishing to harvest the crop with a conventional 'head' on the combine. Two rows 20 cm apart (paired rows) can be fed into a maize head as though they were a single row, allowing some of the advantages of narrow rows without the practical disadvantages. The objective of this study was to evaluate the effects of different population densities and planting patterns on the yield and yield components of leafy reduced-stature maize hybrids.

MATERIALS AND METHODS

Selection of the leafy reduced stature hybrids used in this work was based on leaf area above the ear, leaf number above the ear, and yield potential as determined in previous trials (Modarres, 1995). The LRS hybrid used by Modarres (1995) was the first one combining both traits and having reasonable yields available [1240-6-2 x (CM 174rd1 x W117rd1)]. During the latter part of his research (Modarres, 1995) identified a second promising LRS hybrid [1306-6-2 x (CM174rd1 x W117rd1)], which we have tested and compared with the hybrid used by Modarres (1995). This represented the first chance to test two LRS hybrids together.

Five maize hybrids {two leafy-reduced stature (LRS1 and LRS2) three-way crosses [LRS1 cross: (CM174rd1 x W117rd1) x 1240-6-2, LRS2 cross: (CM174rd1 x W117rd1) x 1306-6-2], one three-way NLRS cross [(CM174 x W117rd1) x LGP] and two conventional hybrids as control} were tested in 1995. Where 1240-6-2 and 1306-6-2 are inbreds that carry both Lfy and rd1 traits, which are desended from CM7 and CO255 respectively, while CM174rd1 and W117rd1 are inbreds that carry the rd1 traits. The control hybrids were Pioneer 3979, (<2500 CHU), and Pioneer 3902, (2600-2700 CHU). The acronym LGP stands for Lethbridge gene pool, an early-maturity synthetic developed at the Lethbridge, Alberta, Station of Agriculture and Agri-Food Canada. Plants were seeded on 18 May and 1 June 1995 for locations 1 and 2 respectively. The experiments were designed as a split-split-plot with the main plots arranged in a randomized complete block design with three blocks. The maize was planted at two plant densities (65,000, and 130,000 plants ha^{-1}), which formed the main plots and two planting patterns (single row spacing with 76 cm between rows, and paired rows with 20 cm between rows within the same pair and 56 cm between adjacent pairs). The latter row width is a paired row arrangement which allows a higher plant population density that can still be harvested with a conventional maize combine head.

Planting pattern formed the sub-plot units and hybrids formed sub-sub-plot units. The recommended plant population for conventional hybrids in southwestern Quebec is 65,000 to 75,000 plants ha^{-1}. All plots were hand planted. The 76-cm row spacing plots consisted of three rows and the paired row spacing plots of four rows. The plots were 5 m long. Plots were over-seeded and thinned to the required plant densities three weeks after emergence. The centre row of each 76-cm row spacing plot and the centre two rows of each paired row plot were used for plant measurements and yield determinations.

The experiment was conducted at the E.A. Lods Agronomy Research Centre of the Macdonald Campus of McGill University, (Ste. Anne de Bellevue, Quebec, 45^0 26'N latitude; FAO 300-400) on fertilized Courval sandy soil (fine-silty, mixed, nonacid, frigid Humaquept) at site 1 and on Bearbrook clay soil (fine, mixed, nonacid, frigid Humaquept) at site 2 in 1995. Plots were fertilized with 350 kg ha^{-1} of 30-0-10 N, P_2O_5, K_2O prior to planting, and 100 kg ha^{-1} NH_4NO_3-N three weeks after plant emergence. Weeds were controlled with Sutan herbicide (S-ethyl diisobutyle thiocarbonate, Ciba-Geigy, Canada, LTD, Mississauga, ON) applied at 5.5 L ha^{-1} pre-planting and a mixture of atrazine (2 chloro-4-ethylamino-6-isoprophylamino-1,3,5-triazine) and Bentazon [3-isopropyl-1H-2,1,3-benzothiadiazine-4(3h)-one-2, 2 dioxide, BASF, Canada. Inc; Rexdale, ON], (1:1), applied at 3 kg ha^{-1} at the three- to four-leaf stage for both sites.

The following data were collected from each plot: number of kernel rows per ear, kernel number per row, single plant grain yield, grain yield t ha^{-1}, grain moisture content, harvest index, ear diameter, ear length, and husk dry weight.

At physiological maturity, as determined by the black layer method (Aldrich, 1943; Daynard and Duncan, 1969), four plants per plot were randomly selected and cut at ground level. After the fresh weight was taken the sub-samples were dried to a constant weight at 80 ^{0}C for grain moisture determination; the same sample was used to determine yield component variables. The ears of all plants in a 3 m^2 area were hand picked and used for grain yield determination. Ears were shelled mechanically, grain yield was determined, and plot yields were expressed at 15.5% moisture on t ha^{-1} and per plant bases.

All data were subjected to analysis of variance on a per location basis with the PROC GLM Procedure of SAS (SAS Institute, 1994). Contrasts between the four maize hybrids were conducted for all variables (Steel and Torrie, 1980). Simple means comparisons were made with a protected LSD test, if ANOVA indicated the presence of differences. Effects of plant density, planting patterns and hybrids were examined jointly to test for the presence of interactions between the three factors.

RESULTS AND DISCUSSION

Crop establishment

The 1995 growing season was warm and dry in the month of June (Table 1). A period of hot dry weather began between the planting of site one and site two. Thus plants at site one established under conditions of much better moisture availability. Because of this difference and the better soil type of site one than site two the values of most measured variables were lower at site two than site one.

Yield components

Differences were detected among plant population densities for all variables except kernel row number per ear and harvest index at both locations; differences among hybrids existed for all variables (Tables 2 and 3). There were also population by hybrid interactions for kernel number per row, ear diameter, ear length, harvest index, and husk dry weight at location 1. The same interactions occurred at location 2 except for husk dry weight. Effects of row spacing existed only for single plant grain yield and grain yield (t ha^{-1}) at both locations. There were no interactions between plant population densities and planting pattern at either location (Table 4). Kernel row number was not affected by population density or planting pattern, however there were differences between hybrids. Pioneer 3979 had fewer kernel rows per ear than the other hybrids tested (Tables 2 and 3). Kernel number per row was affected only by population density and hybrid. Grain sink size is strongly associated with kernel number in grain crops, and kernel number is a function of plant dry matter accumulation (Fischer, 1985). All hybrids had higher kernel number per row values at lower population densities, however as plant density increased the most affected hybrids were the conventional ones indicating a greater tolerance of higher plant population densities by reduced-stature hybrids. Similar results were reported for grain yield differences by shade intolerant hybrids, which produced more barren ears under shade than more shade tolerant hybrids (Stinson and Moss, 1960). In general, shading, high plant density, and other environmental stresses that reduce plant photosynthesis reduce per plant grain yield, in part due to the relationship between kernels per plant and plant photosynthesis (Stinson and Moss, 1960).

Grain yield

Single plant grain yields were higher at low plant population densities in paired rows than at higher densities in paired rows for all hybrids at both locations (Table 4). The single plant grain yields of the LRS1, LRS2, and NLRS hybrids were little affected by high population density (11.6, 13.9 and 16.9% reductions, respectively) while the reductions in single plant grain yield were 56.1 and 57.9% for Pioneer 3979 and 3902, respectively, at location 2 (Table 4). These higher reductions for conventional hybrids were probably because the conventional hybrids have bigger and more horizontally oriented leaves such that mutual shading causes a large reduction in single plant grain yield. Yield reductions due to mutual shading of maize plants have previously been demonstrated (Pendleton and Hammond, 1968).

Grain yields were higher in the paired row spacing than single row spacing for all hybrids at both plant population densities. The grain yields were increased at the high population density for the two LRS and NLRS hybrids, whereas the grain yields of Pioneer 3979 and 3902 were decreased by 7.1, 23.9% at locations1 and 5.9, 20.9% at locations 2 respectively, (Table 3). Reductions in grain yield at higher population densities may have resulted from fewer flower initials being formed prior to flowering, poor pollination resulting from asynchrony of tasselling and silking, or from abortion of kernels after fertilization. Reductions in maize grain yields due to these factors have been demonstrated in previous research reports. (Daynard and Muldoon 1983; Karlen and Camp 1985; Hashemi-Dezfouli and Herbert 1993).

At lower plant densities LRS and NLRS types generally produced more than one ear per plant, while the conventional hybrids produced only one. As yield of LRS and NLRS hybrids increased to higher plant population densities than the NLNS (conventional) hybrids, this result suggests that hybrids which are able to produce grain on more than one ear (prolific hybrids) may be more density tolerant than hybrids with only one ear. A similar result was reported for prolific types by Russell (1968).

Ear diameter and ear length

Ear diameter and ear length were lower at the high population density than the low population density, with the ear lengths of the conventional hybrids being most strongly reduced by the higher population density. However, no effect of planting pattern was detected on these two variables (Tables 2 and 3). At both locations ear diameter and ear length were higher for the conventional control hybrids than the others tested. Ear diameter and ear length influenced final ear weight. Baenziger and Glover (1980) reported that ear weight, ear diameter, ear length and ear kernel number were increased, but yield was decreased by low population densities.

Harvest index

Population density and row spacing did not affect harvest index, whereas there were effects of hybrid on harvest index (Tables 2 and 3). Tollenaar (1989) reported that recent hybrids maintain a constant harvest index as plant density increases because they are less prone to plant barrenness at high densities than older hybrids. Vatikonda and Hunter (1983), Allen et al. (1991), and Cox et al. (1994) reported that harvest index does not have a strong positive relationship with total dry matter yields. Harvest index was not different among NLRS, and the conventional control hybrids (0.49) but the LRS1 and LRS2 hybrids had a higher average harvest index (0.57) value than the others (Tables 2 and 3).

Grain moisture content and husk dry weight

LRS and NLRS hybrids had lower moisture contents than the conventional hybrids at both locations (Tables 2 and 3). As population density increased there was a greater increase in grain moisture content for the conventional hybrids, which was probably due to increased shading. However this was not the case in the LRS and NLRS hybrids, probably because of their vertically oriented and smaller leaves. Maize hybrids differ in the rate at which moisture is lost from the grain during maturation (Cross and Kabir, 1989). Most hybrids are physiologically mature at grain moisture contents of about 30%, while the ideal moisture content for mechanical harvesting is about 25% (Oslon and Sander, 1988). Harvest can occur at kernel moisture levels above 30% but field losses and artificial drying costs are greater (Hicks et al., 1976). Therefore, LRS and NLRS hybrids are more likely to achieve desirable grain moisture contents in short-season environments.

Husk dry weight declined as population density increased among all hybrids at both locations (Tables 2 and 3). Salvador and Pearce (1988) reported the importance of husks in the maintenance of an adequate moisture and temperature environment for the developing ear and as a storage organ for remobilizable assimilate, as demonstrated by the fact that husk removal reduced grain yield much more than could be accounted for by the loss of husk photosynthesis. Husk dry weight was higher for conventional hybrids than LRS and NLRS hybrids. Husks are known to provide a large resistance to water loss (Troyer and Ambrose, 1971; Hicks et al. 1976). Reducing the number of husks has been reported to increase the grain drying rate (Troyer and Ambrose, 1971). This character may be useful in breeding to select material with fast-drying properties for short-season areas.

Conclusions

The two Leafy reduced-stature hybrids evaluated here matured earlier with lower moisture contents, and tolerated high population density better than the conventional hybrids. They also produced grain yields that are reasonable for the area where the research was conducted, particularly in paired rows and at high population density. At a high plant population density, most of the yield component values were higher for the LRS hybrid than the NLRS and Pioneer 3979 hybrids. The paired row spacing gave higher yields than the conventional single-row spacing at both plant population densities. The paired row spacing should allow harvest with conventional equipment. Harvest index was higher for the LRS hybrid than the others so that grain yields comparable to the conventional checks were achieved with lower total biomass production levels. Therefore, LRS hybrids may show promise for production in shorter-season areas with fewer corn heat units available, and where maize cultivation is not now economical.

Table.3.1. Monthly mean temperature and total rainfall during the 1995 growing season and 30 year averages.

	1995		Averages *	
Month	Mean temperature (^{0}C)	Rainfall (mm)	Mean temperature (^{0}C)	Rainfall (mm)
May	12.6	81.1	13.1	70.6
June	20.6	73.0	18.1	88.3
July	22.1	152.6	21.1	89.7
August	20.7	139.0	19.8	92.6
September	13.7	86.2	14.7	97.9

* 30-yr averages

Table.3.2. Simple mean values of kernel row number per ear (KRN), kernel number per row (KNR), ear diameter (ED), ear length (EL), harvest index (HI), grain moisture contents (GMC), and husk dry weight (HDW) of five maize hybrids at location 1.

Population (plants ha^{-1})	Hybrids	KRN	KNR	ED (cm)	EL (cm)	HI	GMC (%)	HDW (g)
65,000	LRS1	15.3	29.8	3.7	14.5	0.57	27.4	18.5
	LRS2	14.6	29.8	3.7	14.2	0.53	26.2	16.3
	NLRS	14.8	25.6	3.4	12.3	0.48	26.0	15.0
	P3979	12.9	34.3	4.3	15.5	0.49	29.7	24.9
	P3902	14.9	37.4	4.8	17.4	0.54	33.2	34.8
130,000	LRS1	15.1	26.7	3.3	12.8	0.59	28.0	13.2
	LRS2	15.2	26.7	3.4	12.4	0.58	27.3	12.9
	NLRS	14.8	24.3	3.2	11.0	0.54	27.4	11.2
	P3979	12.8	27.1	3.8	13.3	0.50	31.9	21.3
	P3902	15.0	26.6	3.6	13.6	0.46	35.3	22.3
CV		5.2	6.9	3.3	4.7	8.1	5.9	4.8
LSD_a		-	4.5	0.4	1.7	-	3.7	2.1
LSD_b		0.9	2.3	0.2	0.8	0.1	2.0	1.1
Populations (P)		ns	**	*	*	ns	**	**
Planting Patterns (PP)		ns	ns	ns	ns	ns	ns	ns
P * PP		ns	ns	ns	ns	ns	ns	ns
Hybrids (H)		**	**	**	**	**	**	**
P * H		ns	**	**	**	**	ns	**
PP * H		ns	ns	ns	ns	ns	ns	ns
P * PP * H		ns	ns	ns	ns	ns	ns	ns

Abbrevations: LRS1, Leafy reduced-stature 1; LRS2, Leafy reduced-stature 2; NLRS, Non-leafy reduced-stature; P3979, Pioneer (early check); P3902, Pioneer (medium check). LSD_a is for comparing two main plot means (averaged over all subplot factors), while LSD_b is for comparing two sub-subplot means (averaged over all subplot factors). *, Significant at the 0.05 level; **, Significant at the 0.01 level; and ns, not significant.

Table.3.3. Simple mean values of kernel row number per ear (KRN), kernel number per row (KNR), ear diameter (ED), ear length (EL), harvest index (HI), grain moisture contents (GMC), and husk dry weight (HDW) of five maize hybrids at location 2.

Populations (plants ha^{-1})	Hybrids	KRN	KNR	ED (cm)	EL (cm)	HI	GMC (%)	HDW (g)
65,000	LRS1	14.2	27.0	3.6	12.4	0.56	26.1	14.4
	LRS2	14.4	25.8	3.7	12.1	0.54	26.3	13.4
	NLRS	14.0	22.8	3.0	11.3	0.43	25.4	11.6
	P3979	12.3	30.4	3.9	14.2	0.52	29.4	21.1
	P3902	14.2	36.5	4.1	13.9	0.52	33.3	24.4
130,000	LRS1	14.3	23.7	3.3	11.2	0.58	28.3	11.4
	LRS2	14.0	22.6	3.2	11.0	0.58	28.1	11.6
	NLRS	13.5	19.6	3.0	9.2	0.49	27.2	7.5
	P3979	12.1	24.7	3.4	12.1	0.45	32.5	17.8
	P3902	14.3	24.9	3.6	11.4	0.45	35.9	20.9
CV		6.6	8.1	3.5	5.2	9.8	6.4	6.5
LSD$_a$		-	4.9	0.3	1.4	-	4.2	2.3
LSD$_b$		1.1	2.5	-	0.7	0.1	2.0	1.2
Populations (P)		ns	**	**	**	ns	**	**
Planting Patterns (PP)		ns	ns	ns	ns	ns	ns	ns
P * PP		ns	ns	ns	ns	ns	ns	ns
Hybrids (H)		**	**	**	**	**	**	**
P * H		ns	**	**	*	**	ns	ns
PP * H		ns	ns	ns	ns	ns	ns	ns
P * PP * H		ns	ns	ns	ns	ns	ns	ns

Abbrevations: LRS1; LRS2, Leafy reduced-stature 2; NLRS, Non-leafy reduced-stature; P3979, Pioneer (early check); P3902, Pioneer (medium check). LSD$_a$ is for comparing two main plot means (averaged over all subplot factors), while LSD$_b$ is for comparing two sub-subplot means (averaged over all subplot factors). *, Significant at the 0.05 level; **, Significant at the 0.01 level; and ns, not significant.

Table.3.4. Simple mean values of single plant grain yield, grain yield (t ha^{-1}) of hybrids

			Location 1		Location 2	
Populations (plants ha^{-1})	Planting patterns (m)	Hybrids	SPGY	GYTH	SPGY	GYT
65,000	0.76	LRS1	107.9	7.0	85.6	5.6
		LRS2	101.7	6.6	79.1	5.1
		NLRS	65.6	4.3	47.8	3.1
		P3979	133.2	8.7	118.0	7.7
		P3902	189.6	12.3	156.0	10.1
	0.56	LRS1	119.0	7.7	104.7	6.8
		LRS2	116.2	7.6	104.2	6.8
		NLRS	76.1	4.9	54.6	3.6
		P3979	144.8	9.4	132.4	8.6
		P3902	196.6	12.8	169.7	11.0
130,000	0.76	LRS1	96.9	12.6	69.2	9.0
		LRS2	90.4	11.8	68.5	8.9
		NLRS	57.6	7.5	43.6	5.7
		P3979	62.6	8.1	44.9	5.8
		P3902	85.0	11.0	60.2	7.8
	0.56	LRS1	100.2	13.0	80.2	10.4
		LRS2	97.1	12.6	74.1	9.6
		NLRS	60.1	7.8	46.5	6.1
		P3979	59.6	7.8	51.1	6.6
		P3902	77.5	10.1	69.3	9.0
CV			8.9	7.7	11.4	11.0
LSD$_a$			12.1	0.9	15.9	1.1
LSD$_b$			5.2	0.5	9.3	0.7
LSD$_c$			22.7	1.7	24.3	2.0
LSD$_d$			10.6	0.8	11.2	1.0
Populations (P)			**	**	**	*
Planting Patterns (PP)			*	*	**	**
P * PP			*	*	ns	ns
Hybrids (H)			**	**	**	**
P * H			**	**	**	**
PP * H			ns	ns	ns	ns
P * PP * H			ns	ns	ns	ns

Abbrevations:LRS1, LRS2, Leafy reduced-stature 1 & 2 respectively; NLRS, non-leafy reduce stature; P3979, P3902 , Pioneer (early & medium check), (SPGY), Single plant grain yield, (GYTH), Grain yield (t ha^{-1}) . LSD$_a$ is for comparing two main plot means (averaged over all su subplot factors), LSD$_b$ is for comparing two subplot means (averaged over all sub-subplot factor LSD$_c$ is for comparing two main plot means (averaged over all subplot factors),while LSD$_d$ is fo comparing two sub-subplot means (averaged over all subplot factors). *, Significant at the 0.05 level; **, Significant at the 0.01 level; and ns, not significant.

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Preface of Chapter 4

In the experiment described in Chapter 3, the yield potential of Leafy reduced-stature hybrids at high plant density was identified, but it was not possible to identify the optimum population for LRS hybrids because only two plant densities were used in that work. This experiment was designed to evaluate the effects of four plant densities on the yield and yield components of a Leafy reduced-stature hybrid along with non-leafy reduced-stature and conventional maize hybrids in order to determine the optimum plant density for Leafy reduced-stature hybrids. The manuscript has been accepted for publication in the journal of Agronomy and Crop Science and has been co-authored by myself, R.I. Hamilton, L.M. Dwyer, D.W. Stewart, and D.L. Smith.

EFFECTS OF POPULATION DENSITY ON THE YIELD AND YIELD COMPONENTS OF LEAFY REDUCED-STATURE MAIZE IN A SHORT-SEASON AREA.

ABSTRACT

Maize hybrids that yield well, mature early, and tolerate higher population densities better than currently available hybrids would be more suitable for production in short-season areas. Leafy reduced-stature maize hybrids, which have only recently been developed, have traits which address these criteria. The objective of this study was to evaluate the effects of different population densities (50,000; 100,000; 150,000; and 200,000 plants ha^{-1}) on the yield and yield components of one Leafy reduced-stature (LRS) hybrid, one non-leafy reduced-stature (NLRS) hybrid, and two conventional control hybrids (Pioneer 3979, <2500 CHU; and Pioneer 3902, 2600-2700 CHU) at two locations. All hybrids had the highest kernel number per row, and single plant grain yields at the lowest population densities, however as plant density increased these variables decreased more in the conventional hybrids than the LRS and NLRS hybrids, which demonstrates the greater tolerance of the reduced-stature hybrids to the stresses associated with higher plant densities. Grain yield was highest for all hybrids, except for NLRS, at 100,000 plants ha^{-1}. The highest yields at site 1 and 2 were for the LRS hybrid (11.4 vs 9.8 t ha^{-1} respectively) and Pioneer 3902 (12.0 vs 10.4 t ha^{-1} respectively). The LRS hybrid matured before either of the conventional hybrids and outyielded Pioneer 3979 at both sites. Harvest index was not affected by population density and this value was not different among the NLRS and conventional hybrids. However, the harvest index of the LRS hybrid was greater than the others. LRS and NLRS hybrids had lower moisture contents and earlier maturities than conventional hybrids. Rapid growth of the first ear, higher yield per unit leaf area, and a higher harvest index are indications that LRS hybrids should be more tolerant of higher population densities than the conventional hybrids.

Key words: Population density, Leafy reduced-stature, grain yield, grain moisture.

INTRODUCTION

A serious problem for maize production in short-season areas is the low final leaf area developed by the plants. This is mainly due to smaller plant stature, and to reduced leaf number and size for hybrids adapted to short-season conditions (Chase and Nanda, 1967; Hunter et al., 1974). By manipulating photoperiod, Hunter (1980) was able to increase leaf area per plant and grain yields of short season maize. Stringfield (1956) found that increasing plant population to maximum levels had a greater effect on the yield of earlier maturing than later maturing hybrids. It seems reasonable that optimum use of the limited growing period for maize is essential to maximize grain yield in short-season areas.

One way to increase leaf area index is to increase planting density (Olson and Sander, 1988). Alessi and Power (1975) studied early maturing maize hybrids in the northern regions of the great plains and found that increasing plant densities up to 74,000 plants ha^{-1} produced LAIs as high as 4.9, although this was dependent on hybrid and season. Planting at high plant densities is a technique that can be used to increase crop yield. While single plant yield decreases due to an increase in plant density, total light interception by the canopy is increased and so is total grain yield. The response of grain yield per unit area to increased plant density is parabolic (Karlen and Camp, 1985). A decrease in grain yield at superoptimal plant densities is due to increased ear barrenness (Buren et al., 1974; Daynard and Muldoon, 1983), decreased numbers of kernels per ear (Iremiren and Milbourn, 1980; Tetio-Kagho and Gardner, 1988), or both.

For many years plant population has received increased attention as a method of increasing crop yields. Dungan et al. (1958) found that maize (*Zea mays* L.) ear weight per plant decreased linearly as plant population increased, as long as yield per hectare increased. Prine and Schorder (1946) suggested the main factor causing the decrease in ear number and yield per plant was the mutual shading of plants. Pendleton and Hammond (1969) found that the relative photosynthetic potential of maize leaves in the top one-third of the canopy was twice as high as the middle leaves and five times as high as leaves in the bottom third.

Selecting an appropriate density is important in the establishment of crop production systems and many investigations have dealt with crop responses to population density. Under weed-free conditions, maize yield increases with an increase in plant density, until the optimum plant density is reached (Duncan, 1954; Tollenaar, 1991).

The optimum plant density may not be the same for all hybrids within a maturity group e.g. taller, leafier genotypes with bigger ears may have an optimum plant density that is lower than shorter smaller-eared genotypes (Carmer and Jacobs, 1965; Warren, 1963). Maize hybrids used in temperate regions generally have optimum planting densities close to 7.0 plants m^{-2} (Russell, 1985; Tollenaar, 1991).

It is also very important to select hybrids that are tolerant of high plant densities. Buren et al. (1974) reported that density tolerant maize hybrids are characterized by rapid completion of silk extrusion, rapid growth of the first ear and first appearance of ear silk, prolificacy, smaller tassel size, and greater efficiency in the production of grain per unit leaf area. The semi-reduced-stature, compact (ctl) and reduced-stature (rd1) mutants in inbred backgrounds have been shown to be more resistant to population stress than noncompact and normal stature inbred lines (Nelson and Ohlrogge, 1957).

Plants bearing the Leafy (Lfy1) and reduced-stature (rd1) gene were brought together to produce Leafy reduced-stature hybrids. Modarres (1995) has shown that Leafy-reduced stature (LRS) hybrids have the potential to yield well and mature early, and that they yield better at 130,000 plants ha^{-1} than 65,000 plants ha^{-1}. There has been no previous effort at determining the optimum population density for LRS hybrid or to compare the effects of more than two population densities on yield components of LRS hybrid and conventional hybrids.

Based on the above literature it can be hypothesized that maize hybrids which produce more leaf area than current hybrids and develop both leaf area and mature grain more rapidly than current hybrids would be more suitable to short season areas.

The leafy trait allows a more rapid development of leaf area while reduced stature plants generally develop and mature rapidly. The objective of this study was to evaluate the effects of different population densities on the yield and yield components of Leafy reduced-stature maize hybrids.

MATERIALS AND METHODS

Selection of the leafy reduced stature hybrids used in this work was based on leaf area above the ear, leaf number above the ear, and yield potential as determined in previous trials (Modarres, 1995).

Four maize hybrids [(one three-way LRS cross: (CM174rd1 x W117rd1) x 1240-6-2, one three-way NLRS cross: (CM174rd1 x W117rd1) x LGP cross, and two conventional hybrids as controls) were tested in 1995. Where 1240-6-2 is an inbred that carries both Lfy and rd1genes, the parent which was CM7, and CM174rd1 and W117rd1 are inbreds that carry the rd1gene. The acronym LGP stands for Lethbridge gene pool, an early maturity synthetic developed at the Lethbridge, Alberta, Station of Agriculture and Agri-Food Canada. The control hybrids were Pioneer 3979, (<2500 CHU), and Pioneer 3902, (2600-2700 CHU). Plants were seeded on 18 May and 1 June 1995 for locations 1 and 2 respectively. The experiments were designed as a split-plot with the main plots arranged in a randomized complete block design with three blocks. The maize was planted at four plant densities (50,000; 100,000; 150,000; and 200,000 plants ha^{-1}), which formed the main plots. The recommended plant population for conventional hybrids in southwestern Quebec is 65,000 to 75,000 plants ha^{-1}. The hybrids formed the sub-plots. All plots were hand planted. Each plot consisted of three rows 76-cm apart and 5 m long. Plots were over-seeded and thinned to the required plant densities three weeks after emergence. The centre row of each plot was used for plant measurements and yield determinations.

The experiment was conducted at the E.A. Lods Agronomy Research Centre of the Macdonald Campus of McGill University, (Ste. Anne de Bellevue, Quebec, 45^0 26'N latitude; FAO 300-400) on fertilized Courval sandy soil (fine-silty, mixed, nonacid, frigid Humaquept) at location 1 and on Bearbrook clay soil (fine, mixed, nonacid, frigid Humaquept) at location 2 in 1995. Plots were fertilized with 350 kg ha^{-1} of 30-0-10 N, PLO, K_2O prior to planting, and 100 kg ha^{-1} NH_4NO_3-N three weeks after plant emergence. Weeds were controlled with Sutan herbicide (S-ethyl diisobutyle thiocarbonate, Ciba-Geigy, Canada, LTD, Mississauga, ON) applied at 5.5 L ha^{-1} pre planting and a mixture of atrazine (2 chloro-4-ethylamino-6-isoprophylamino-1,3,5-triazine) and Bentazon [3-isopropyl-1H-2,1,3-benzothiadiazine-4(3h)-one-2, 2 dioxide, BASF, Canada. Inc; Rexdale, ON],(1:1), applied at 3 kg ha^{-1} at the three- to four-leaf stage for both locations.

The following data were collected from each plot: number of kernel rows per ear, kernel number per row, single plant grain yield, grain yield t ha^{-1}, grain moisture content, harvest index, ear diameter, ear length, and husk dry weight. At physiological maturity (black layer; Aldrich, 1943; Daynard and Duncan, 1969) four plants per treatment were randomly selected and cut at ground level. After the fresh weight was taken and sub-samples were dried to a constant weight at 80 ^{0}C for grain moisture determination; the same sample was used to determine yield component variables. The ears of all plants in a 3 m^2 area were hand picked and used for grain yield determination. Ears were shelled mechanically, grain yield was determined, and plot yields were expressed at 15.5% moisture on a t ha^{-1} and per plant basis.

All data were subjected to analysis of variance on a per location basis with the PROC GLM Procedure of SAS (SAS Institute, 1994). Contrasts between the four maize hybrids were conducted for all variables (Steel and Torrie, 1980). Simple means comparisons were made with a protected LSD test, if ANOVA indicated the presence of differences. Effects of plant density, and hybrids were examined jointly to test for the presence of interactions between the two tested factors.

RESULTS AND DISCUSSION

Crop establishment

The 1995 growing season was warm and dry in the month of June (Table 1). A period of hot dry weather occurred between the planting of site one and two. Thus plants at site one established under conditions of much better moisture availability than those at site two. Because of this difference and the better soil type of site one the values of most measured variables were lower at site two than site one.

Yield components

Differences were detected among plant population densities and hybrids for all variables except kernel rows per ear, harvest index, and ear length at location 1 and kernel rows per ear, grain moisture content, and harvest index at location 2 (Tables 2 and 3). Interactions between plant densities and hybrids existed for all variables except kernel rows per ear and harvest index at location 1 and for kernel rows per ear, grain moisture content, harvest index, ear diameter, and ear length at location 2 (Tables 2 and 3).

Kernel row number was not affected by population density, however there were differences between hybrids. Pioneer 3979 had fewer kernel rows per ear than the other hybrids tested (Tables 2 and 3). Kernel number per row was affected by population density and hybrid. Grain sink size is strongly associated with kernel number in grain crops, and kernel number is a function of plant dry matter accumulation (Fischer, 1985). All hybrids had higher kernel number per row values at lower population densities, however as plant density increased the most affected hybrids were the conventional ones, indicating a greater tolerance of higher plant population densities by the reduced stature hybrids. Similar results were reported for grain yield differences by shade intolerant hybrids, which produced more barren ears under shade than more shade tolerant hybrids (Stinson and Moss, 1960). In general shading, high plant density, and various environmental stresses that reduce plant photosynthesis reduce per plant grain yield, in part due to the relationship between kernels per plant and plant photosynthesis (Stinson et al., 1960).

Grain yield

Single plant grain yields were higher at lower plant population densities than higher densities for all hybrids (Tables 2 and 3). The single plant grain yields of the LRS and NLRS hybrids were not different between 50,000 and 100,000 plants ha^{-1}. The single plant grain yields of the NLRS hybrid increased as the plant population was increased at both locations, probably because these plants have fewer leaves above the ear and smaller leaves and where not shading one another much even at 200,000 plants ha^{-1}. The single plant grain yield of the conventional hybrids declined as population increased. At 200,000 plants ha^{-1} all hybrids had similar single plant grain yields (Tables 2 and 3).

Grain yield was highest for all hybrids except for NLRS at 100,000 plants ha^{-1} with the LRS hybrid and Pioneer 3902 having the highest yields (11.4 and 12.0 t ha^{-1}, respectively). Above 100,000 plants ha^{-1} the yields of the LRS hybrid was substantially higher than those of the two conventional controls and the NLRS hybrids (Tables 2 and 3). The relationship between grain yield (Y) and plant population density (P) could be described by a quadratic function. The equations were ($Y = -1773.07 + 982.31P - 29.35P^2$ ($r^2 = 0.12$ and $P \leq 0.05$); $Y = 873.88 + 26.46P + 11.01P^2$ ($r^2 = 0.34$ and $P \leq 0.05$) and $Y = -3488.66. + 1398.78P - 46.35P^2$ ($r^2 = 0.16$ and $P \leq 0.05$) for LRS, NLRS, and conventional hybrids, respectively. Where yield (Y) was expressed in grams and plant numbers (P) were expressed on a per m^{-2} basis. Reductions in grain yield at higher population densities may have resulted from fewer flower initials being formed prior to flowering, poor pollination resulting from asynchrony of tasselling and silking, or from abortion of kernels after fertilization. Reductions in maize grain yields due to these factors have been demonstrated in previous research reports (Daynard and Muldoon 1983; Karlen and Camp 1985; Hashemi-Dezfouli and Herbert 1992). In this study the reductions of grain yield at high plant population densities have been clearly shown, with reductions in kernel number per row, ear length and ear diameter.

At lower plant densities LRS and NLRS types generally produced more than one ear per plant, while the conventional hybrids produced only one. As yield of LRS and NLRS hybrids increased at higher plant population densities than the NLNS hybrids, it would seem that hybrids which are able to produce grain on more than one ear (prolific hybrids) may be more density tolerant than hybrids producing only one ear. A similar result was reported for prolific types by Russell (1968).

Ear diameter and ear length

These two variables declined as population density increased (Tables 2 and 3); the conventional hybrids being most strongly affected. At both locations ear diameter and ear length were higher for the conventional control hybrids than the others tested. Ear diameter and ear length, along with kernel weight, were the variables which had the greatest influences on final ear weight. Baenziger and Glover (1980) reported that ear weight, ear diameter, ear length and ear number were increased, but yield was decreased by low population density.

Harvest index

Population density did not affect harvest index (Tables 2 and 3). Tollenaar (1989) reported that recent hybrids maintain a constant harvest index as plant density increases because they are less prone to plant barrenness at high densities than older hybrids. Vatikonda and Hunter (1983), Allen et al. (1991), and Cox et al. (1994) reported that harvest index does not have a strong positive relationship with total dry matter yields. Harvest index was not different among NLRS and the conventional control hybrids (0.51 vs 0.50) but the LRS hybrid had a higher harvest index (0.58) value than the others (Tables 2 and 3).

Grain moisture content and husk dry weight

LRS and NLRS hybrids had lower moisture contents than the conventional hybrids at both locations (Tables 2 and 3). As population density increased there was a sharp increase in grain moisture content for the conventional hybrids, which was probably due to increased shading. However this was not the case in the LRS and NLRS hybrids, probably because of their more vertically oriented and smaller leaves. Maize hybrids differ in the rate at which moisture is lost from the grain during maturation (Cross and Kabir, 1989). Most hybrids are physiologically mature at a grain moisture content of about 30%, while the ideal moisture content for mechanical harvesting is about 25% (Olson and Sander, 1988). Harvest can occur at kernel moisture levels above 30% but field losses and artificial drying costs are greater (Hicks et al., 1976). Therefore, LRS and NLRS hybrids are more likely to achieve desirable grain moisture contents in short-season environments.

Husk dry weight declined as population density increased among all hybrids at both locations (Tables 2 and 3). There were positive relationships between dry husk weight and grain yield (t ha^{-1}) for all hybrids. Husk may play an important role in yield production. Salvador and Pearce (1988) reported the importance of husks in the maintenance of an adequate moisture and temperature environment for the developing ear and as a storage organ for remobilizable assimilate, as demonstrated by the fact that husk removal reduced grain yield much more than could be accounted for by the loss of husk photosynthesis. Husk dry weight was higher for conventional hybrids than LRS and NLRS hybrids. Husks are known to provide a large resistance to water loss (Troyer and Ambrose, 1971; Hicks et al. 1976). In this study a positive relationship was seen between husk dry weight and grain moisture content. The correlation between husk dry weight and grain moisture contents for all hybrids in the two locations was positive and significant ($p \leq 0.01$, $r = 0.42$). Reducing the number of husks has been reported to increase the grain drying rate (Troyer and Ambrose, 1971). This character might be useful in breeding to select material with fast-drying properties for short-season areas.

In conclusion the LRS hybrid matured earlier with lower moisture contents, gave reasonable grain yields and tolerated high population densities better than the conventional hybrids. At high plant population densities most of the yield and yield component values were higher for the LRS hybrid than the NLRS and Pioneer 3979 hybrids. These characteristics are potentially very useful and advantageous for short-growing season areas. The optimum plant density for LRS hybrid is expected to be higher than the conventional hybrids and probably lies between 100,000 and 150,000 plants ha^{-1}, because this hybrid was less affected by higher population densities. Harvest index was higher for the LRS hybrid than the others so that grain yields comparable to the conventional checks were achieved with lower total biomass productions levels. Therefore, LRS hybrids may show promise for production in shorter-season areas with fewer corn heat units available, and where maize cultivation is not now economical.

Table.4.1. Monthly mean temperature and accumulated rainfall during the 1995growing season and 30 year averages.

	1995		Average *	
Month	Mean temperature (°C)	Rainfall (mm)	Mean temperature (°C)	Rainfall (mm)
May	12.6	81.1	13.1	70.6
June	20.6	73.0	18.1	88.3
July	22.1	152.6	21.1	89.7
August	20.7	139.0	19.8	92.6
September	13.7	86.2	14.7	97.9

* 30-yr averages

Table.4.2. Simple mean values of kernel row number per ear (KRN), kernel number per row (KNR), single plant grain yield (SPGY), grain yield t ha^{-1} (GYTH); grain moisture contents (GMC); harvest index (HI); ear diameter (ED); ear length (EL); and husk dry weight (HDW) of maize hybrids at location 1.

Populations (plants ha^{-1})	Hybrids	KRN	KNR	SPGY (g)	GYTH (t ha^{-1})	GMC (%)	HI	ED (cm)	EL (cm)	HDW (g)
50,000	LRS	14.5	29.0	107.4	6.3	27.5	0.58	3.9	14.3	16.4
	NLRS	14.2	25.2	46.3	2.8	28.2	0.46	3.6	13.8	14.3
	P3979	12.0	37.8	126.2	7.4	33.1	0.49	4.1	18.5	23.3
	P3902	14.7	36.8	152.9	9.0	36.1	0.51	4.7	18.4	29.4
100,000	LRS	14.7	27.5	96.6	11.4	27.7	0.60	3.7	13.9	12.5
	NLRS	14.7	24.3	48.9	5.8	28.2	0.51	3.4	11.7	10.7
	P3979	12.7	28.9	93.0	10.9	34.1	0.54	4.1	14.9	16.3
	P3902	14.3	33.3	102.1	12.0	37.1	0.54	4.3	15.9	18.9
150,000	LRS	14.2	26.0	56.7	10.0	27.9	0.59	3.5	12.0	11.0
	NLRS	14.3	22.0	41.2	7.3	28.3	0.52	3.4	10.2	9.6
	P3979	12.3	23.2	48.7	8.6	34.9	0.50	3.9	12.4	14.3
	P3902	14.0	32.2	56.1	9.9	42.1	0.50	4.1	14.8	18.4
200,000	LRS	14.0	24.0	38.5	9.1	28.0	0.57	3.5	11.6	9.8
	NLRS	14.0	21.1	32.3	7.6	28.4	0.51	3.3	10.0	7.9
	P3979	12.0	19.2	33.1	7.8	35.3	0.46	3.7	10.5	11.6
	P3902	13.8	27.1	37.0	8.7	44.1	0.46	4.0	13.2	12.5
C.V		6.3	5.8	11.1	10.0	3.4	8.9	2.3	7.6	12.5
LSD$_a$(0.05)		-	2.7	13.1	1.4	1.9	-	0.1	1.7	3.1
LSD$_b$(0.05)		1.5	2.6	12.3	1.3	1.9	0.1	0.2	1.8	3.4
Populations (P)		ns	**	**	**	**	ns	**	**	**
Hybrids (H)		**	**	**	**	**	**	**	**	**
P * H		ns	**	**	**	**	ns	**	*	**

Abbreviations: LRS, Leafy-reduced stature; NLRS, Non leafy-reduced stature; P3979, Pioneer (early check); P3902, Pioneer (medium check).LSD$_a$ is for comparing means within main plots while LSD$_b$ is for comparing means between main plots. *, Significant at the 0.05 level; **, Significant at the 0.01 level; and ns, not significant.

Table.4.3. Simple mean values of kernel row number per ear (KRN), kernel number per row (KNR), single plant grain yield (SPGY), grain yield t ha^{-1} (GYTH); grain moisture contents (GMC); harvest index (HI); ear diameter (ED); ear length (EL); and husk dry weight (HDW) of four maize hybrids at location 2.

Populations (plants ha^{-1})	Hybrids	KRN	KNR	SPGY (g)	GYTH (t ha^{-1})	GMC (%)	HI	ED (cm)	EL (cm)	HDW (g)
50,000	LRS	14.8	29.8	91.9	5.4	27.7	0.58	4.1	15.6	14.2
	NLRS	13.5	25.0	35.4	2.1	28.2	0.48	3.8	12.0	10.3
	P3979	11.8	33.3	88.9	5.2	31.3	0.50	4.3	17.0	20.6
	P3902	13.8	37.4	134.9	7.9	36.1	0.49	4.4	16.6	21.8
100,000	LRS	14.3	26.3	83.1	9.8	28.0	0.60	4.0	13.0	10.4
	NLRS	13.2	21.8	40.1	4.7	28.1	0.52	3.7	9.6	8.3
	P3979	12.0	27.6	80.0	9.4	32.1	0.55	4.1	14.1	14.3
	P3902	13.5	30.5	88.2	10.4	37.0	0.54	4.1	14.0	13.7
150,000	LRS	13.7	25.8	45.6	8.0	28.0	0.56	3.7	12.2	9.6
	NLRS	13.0	19.2	29.8	5.3	28.7	0.50	3.7	9.3	6.7
	P3979	12.2	22.2	41.8	7.4	34.1	0.51	4.0	13.3	11.7
	P3902	13.7	27.9	49.9	8.8	38.2	0.52	3.9	13.9	13.1
200,000	LRS	14.2	25.8	29.1	6.9	29.2	0.54	3.7	12.0	8.0
	NLRS	13.2	18.0	24.9	5.9	28.9	0.56	3.6	9.0	6.3
	P3979	12.5	20.9	27.2	6.4	34.1	0.41	4.0	12.2	11.6
	P3902	13.8	26.3	31.0	7.3	38.5	0.46	3.8	12.8	12.5
C.V		7.5	6.3	13.5	11.8	3.7	8.9	2.8	8.6	6.3
LSD$_a$(0.05)		-	2.8	13.1	1.4	-	-	0.2	1.9	1.3
LSD$_b$(0.05)		1.7	3.8	13.9	1.7	2.5	0.1	0.2	2.1	1.3
Populations (P)		ns	**	**	**	ns	ns	**	**	**
Hybrids (H)		**	**	**	**	**	**	**	**	**
P * H		ns	**	**	**	ns	ns	ns	ns	**

Abbreviations: LRS, Leafy-reduced stature; NLRS, Non leafy-reduced stature; P3979, Pioneer (early check); P3902, Pioneer (medium check). LSD$_a$ is for comparing means within main plots while LSD$_b$ is for comparing means between main plots. *, Significant at the 0.05 level; **, Significant at the 0.01 level, and ns, not significant.

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Preface of Chapter 5

In the experiment described in Chapter 4, a Leafy reduced-stature hybrid was shown to yield better than other types tested even at higher plant densities than the one used in experiment 1. This manuscript reports the effects of the four plant densities tested in Chapter 4 on the vegetative growth of Leafy reduced-stature along with non-leafy reduced-stature and conventional maize hybrids. The manuscript will be submitted to the journal of Agronomy and Crop Science and will be co-authored by myself, R.I. Hamilton, L.M. Dwyer, D.W. Stewart, and D.L. Smith.

EFFECTS OF POPULATION DENSITY ON THE VEGETATIVE GROWTH OF LEAFY REDUCED-STATURE MAIZE IN A SHORT-SEASON AREA.

ABSTRACT

Maize hybrids that produce more leaves above the ear, have leaf area indices and light interception capabilities similar to conventional hybrids, require fewer maize heat units for flowering and maturity, and tolerate higher population densities should be better adapted to production in short-season areas than currently available hybrids. Leafy reduced-stature maize hybrids, which have only recently been developed, have characteristics which address all of these criteria. The objective of this study was to evaluate the effects of different population densities (50,000; 100,000; 150,000; and 200,000 plants ha^{-1}) on the vegetative growth of one Leafy reduced-stature (LRS), one non-leafy reduced-stature (NLRS), and two conventional control hybrids (Pioneer 3979, <2500 CHU; and Pioneer 3902, 2600-2700 CHU) at two locations. There were no differences among population densities for leaf number above the ear, whereas leaf area index increased as population density increased for all hybrids. The LRS hybrid had a greater average leaf number above the ear than the other hybrids, and had a leaf area index value greater than the NLRS hybrid and similar to the conventional hybrids, but matured substantially before the conventional hybrids. The average percent light interception of the LRS hybrid was similar to the conventional hybrids (80.4 and 81.8%,respectively). The LRS hybrid required fewer corn heat units to reach flowering and maturity and had more time for grain filling than the conventional hybrids. Therefore, LRS hybrids may show promise for production in short-season areas where maize cultivation is not currently economical due to shortness of the growing season.

Key words: Population density, Leafy reduced-stature, Leaf number above the ear, Leaf area index, and Corn heat unit.

INTRODUCTION

In effective crop production efficient utilization of available light is considered as an important factor, and this is strongly affected by crop canopy structure (Daughtry et al., 1983). Canopy light interception and photosynthesis are closely related to leaf area index (LAI).

Maize hybrids grown in a short-season areas have low final LAIs, due to the production of fewer and smaller leaves than hybrids grown in longer season areas; as a result short-season hybrids have lower yields than maize hybrids grown in longer season areas (Chase and Nanda, 1967; Hunter et al., 1974). Hunter (1980) reported that the maximum LAI's of maize in short-season areas with normal plant population densities are low, with values between 2.0 and 2.7. At these LAIs, a maize canopy can intercept about 75% of full sunlight, but with an increase in plant density one can allow the maize canopy to intercept a large percentage of the available sunlight. By manipulating photoperiod growing period, Hunter (1980) was able to increase the leaf area per plant and grain yields of short-season maize. There are two ways of increasing LAI: breeding for increased leaf area per plant, or increasing plant population density. Alessi and Power (1974) studied early maturing maize hybrids in the northern regions of the great plains and found that increasing plant densities up to 74,000 plants ha^{-1} produced LAIs as high as 4.9, although this was dependent on hybrid and season.

Leaf area per plant can be increased by incorporating the "Leafy" trait into hybrids. Plants having the leafy trait are characterized by extra leaves above the ear, low ear placement, highly lignified stalks and leaf parts, early maturity for the level of leaf area development and high yield potential (Shaver, 1983).

Short-season areas [<2600 corn heat units (CHU)] have a limiting number of heat units per season, making a sufficient grain filling period more critical to yield production. Vegetative period duration is positively correlated with leaf number, leaf area and, hence, source size (Muldoon et al., 1984). A longer vegetative period duration increases sink size (Troyer, 1990). Limited growing seasons in short-season areas do not allow breeders to use this strategy, which restricts extension of the vegetative period. To overcome this problem, Hunter (1980) suggested that breeders should select genotypes with rapid leaf area expansion during the vegetative period. Pepper (1974) reported that increased plant population densities can promote utilization of solar radiation by maize canopies. However, the efficiency with which intercepted solar radiation is converted into economic maize yields decreases at higher population densities because of mutual shading (Buren, 1970).

The optimum plant density may not be the same for all hybrids within a maturity group, for instance taller, leafier genotypes may have an optimum plant density that is lower than shorter genotypes; (Carmer and Jacobs, 1965; Warren, 1963). Maize hybrids used in temperate regions generally have optimum planting densities close to 70,000 plants ha^{-1} (Russell, 1985; Tollenaar, 1991). It is also very important to select hybrids that are tolerant of high plant densities. Selecting hybrids that can tolerate high population densities and using an equidistant planting arrangement should provide higher yield for a given plant population density. Buren et al. (1974) reported that density tolerant maize hybrids are characterized by rapid completion of silk extrusion, rapid growth of the first ear, prolificacy, smaller tassel size, and greater efficiency in the production of grain per unit leaf area. The semi-reduced-stature, compact (ctl) and reduced-stature (rd1) mutants in inbred backgrounds have been shown to be more resistant to population stress than noncompact and normal stature inbred lines (Nelson and Ohlrogge, 1957).

Modarres (1995) has shown that Leafy reduced-stature (LRS) hybrids have the potential to produce more leaf area above the ear, and higher LAIs at 130,000 plants ha^{-1} than at 65,000 plants ha^{-1}. However, there has been no previous effort at determining the optimum population density for an LRS hybrid, or comparing the effects of population density on the vegetative growth of an LRS hybrid and conventional hybrids over a range of population densities.

Based on the above literature it can be hypothesized that maize hybrids which produce more leaf area above the ear than current hybrids and develop both leaf area and mature grain more rapidly than current hybrids would be more suitable to short season areas. The leafy trait allows a more rapid development of leaf area while reduced stature plants generally develop and mature rapidly. The objective of this study was to evaluate the effects of different population densities on the vegetative growth of a selected LRS maize hybrid in comparison with conventional and NLRS hybrids.

MATERIALS AND METHODS

Selection of these hybrids was based on leaf area above the ear, leaf number above the ear, and yield potential as determined in previous trials (Modarres, 1995).

Four maize hybrids [(one three-way LRS cross: (CM174rd1 x W117rd1) x 1240-6-2, one three-way NLRS cross: (CM174rd1 x W117rd1) x LGP cross, and two conventional hybrids as controls) were tested in 1995. Where 1240-6-2 is an inbred that carries both Lfy and rd1genes and is the progeny of CM7, while CM174rd1 and W117rd1 are inbreds that carries the rd1gene. The acronym LGP stands for Lethbridge gene pool, an early maturity synthetic developed at the Lethbridge, Alberta, Station of Agriculture and Agri-Food Canada. The control hybrids were Pioneer 3979 (<2500 CHU), and Pioneer 3902 (2600-2700 CHU). Plants were seeded on 18 May and 1 June 1995 for locations 1 and 2, respectively. The experiments were designed as a split-plot with the plots arranged in a randomized complete block design with three replications. The maize was planted at four densities (50,000; 100,000; 150,000; and 200,000 plants ha^{-1}), which formed the main plots. The recommended plant population for conventional hybrids in south western Quebec is 65,000 to 75,000 plants ha^{-1}. The hybrids formed the sub-plots. All plots were hand planted. Each plot consisted of three rows 75 cm apart and 5 m long. Plots were over-seeded and thinned to the required plant densities three weeks after emergence. The centre row of each plot was used for plant measurements.

The experiments were conducted at the E.A. Lods Agronomy Research Centre of the Macdonald Campus of McGill University, (Ste. Anne de Bellevue, Quebec, 45^0 $26'$N latitude; FAO 300-400) on fertilized Courval sandy (fine-silty, mixed, nonacid, frigid Humaquept) soil at location 1 and on Bearbrook clay (fine clay, mixed, nonacid, frigid Humaquept) soil at location 2 in 1995. Plots were fertilized with 350 kg ha^{-1} of 30-0-10 N, P_2O_5, K_2O prior to planting, and 100 kg ha^{-1} NH_4NO_3-N three weeks after plant emergence. Weeds were controlled with Sutan herbicide (S-ethyl diisobutyle thiocarbonate, Ciba-Geigy, Canada, LTD, Mississauga, ON) applied at 5.5 L ha^{-1} pre-planting and a mixture of atrazine (2 chloro-4-ethylamino-6-isoprophylamino -1,3,5-triazine) and Bentazon [3-isopropyl-1H-2,1,3- benzothiadiazine-4(3h)-one-2, 2 dioxide, BASF, Canada. Inc; Rexdale, ON],(1:1), applied at 3 kg ha^{-1} at the three- to four-leaf stage for both locations.

The following data were collected from each plot: Corn heat units from planting to tasselling (CHU-T, when 50% of plants in a plot were shedding pollen), maize heat units from planting to silking (CHU-S, when 50% of plants in a plot had silk showing), plant height (from soil level to the collar of the top leaf), ear height (from soil level to the dominant ear), internode length above the ear (average length of internodes from the dominant ear to the collar of the top leaf), leaf number above the ear, leaf area index (LI-2000 portable area meter, LI-COR, Lincoln, Nebraska), and percent light interception (using a linear quantum sensor, LI-191SB, LI-COR, Inc., Lincoln, Nebraska). After tasselling plant height, ear height, internode length above the ear, and leaf number above the ear were measured on six plants in each plot and averaged to calculate a value for each plot. Daily corn heat units (CHU) were calculated as

$$CHU=\frac{\frac{9}{5}(T_n-4.4)+3.33(T_x-10)-0.084(T_x-10)^2}{2}$$

Where T_n, T_x = minimum and maximum temperature (^{0}C), respectively (Brown and Bootsma, 1993). Heat accumulations were calculated as summations from planting to 50% pollen shed or silking.

All data were subjected to analysis of variance on a per location basis with the PROC GLM Procedure of SAS (SAS Institute, 1994). Contrasts between the four maize hybrids were conducted for all variables (Steel and Torrie, 1980). Simple means comparisons were made with a protected LSD test, if the ANOVA indicated the presence of differences. Effects of plant density, and hybrids were examined jointly to test for the presence of interactions between the two factors.

RESULTS AND DISCUSSION

Crop establishment

The 1995 growing season was warm and dry in the month of June (Table 1). A period of hot dry weather occurred between the planting of sites one and two. Thus, plants at site one established under conditions of much better moisture availability than those at site two. Because of this difference and the better soil type at site one the values of most measured variables were lower at site two than site one.

Vegetative growth

Differences were detected among plant population densities and hybrids for all variables at both locations (Tables 2 and 3) except internode length and leaf number above the ear. There were also differences between the two locations for all variables, mainly due to planting date differences. Interactions between plant densities and hybrids existed for all variables except leaf number above the ear, leaf area index and percent light interception at location 1, but interactions existed only for plant height and ear height at location 2 (Tables 2 and 3). Main effects of population densities for all variables are given in the same tables. All variables were different among hybrids at both locations.

Both plant height and ear height were affected by population density whereas above ear internode length was unaffected (Tables 2 and 3). Plant height and ear height were higher at higher population densities. Increased population density causes plant stems to become thinner and often taller (Gardner et al., 1985). This response to population density was more pronounced for the conventional hybrids than the reduced-stature hybrids. Both conventional hybrids had higher plant and ear heights than LRS and NLRS hybrids (Tables 2 and 3).

There were no differences among population densities for leaf number above the ear, whereas LAI values and percent light interception values increased as population density increased (Table 2 and 3). The relationships between leaf area index (Y) and plant population density (P) could be described by a linear function. The equation was $Y = 1.64 + 0.09P$ ($r^2 = 0.49$ and $P \leq 0.01$) for all hybrids. Several investigations have reported a decrease in leaf area per plant, and an increase in LAI as plant density increased (Larson and Hanway, 1977).

The LRS hybrid had a greater average leaf number above the ear than the other hybrids and the leaf area index and percent light interception were higher for the LRS than the NLRS hybrid (Table 2 and 3). The average percent light interception value for LRS and conventional hybrids were 80.4 and 81.8%,respectively. It is noteworthy that the LRS hybrid, which produced LAI and percent light interception values similar to the conventional hybrids, tasselled (completed leaf area development) substantially before the conventional hybrids. Loomis and Wiliams (1969) suggested that the leaf arrangement in reduced-stature plants might be improved by reducing leaf width, or by arranging the leaves in a whorled pattern. This remains to be tested.

Flowering

Corn heat units from planting to tasselling (CHU-T) and corn heat units from planting to silking (CHU-S) increased as population density increased (Tables 2 and 3). The increases in CHU-T and CHU-S were greater for conventional hybrids than the LRS and NLRS hybrids. The increase in CHU-S between the lowest population density and the highest population density was 106 for the LRS hybrids and 298 for Pioneer 3902 at location 1, and 96 for the LRS hybrid and 118 for Pioneer 3902 at location 2 (Tables 2 and 3). The greater increases in CHU-T and CHU-S for conventional hybrids than for the LRS hybrid was mainly due to the longer vegetative growth period for the conventional hybrids than the LRS and NLRS hybrids. As a result NLRS and LRS hybrids can be said to be more tolerant of high population densities and the associated stresses.

In the northern Corn Belt the season length is normally limited by heat units and by the frost-free period; adapted hybrids seldom, as was the case for the conventional hybrids in this study, complete grain filling prior to the first killing frost. Under these conditions earlier flowering hybrids, like the LRS type, have more time available for the grain-filling period, while later flowering hybrids are left with shorter grain filling periods (Troyer and Brown, 1976; Troyer, 1990).

In conclusion the LRS and NLRS hybrids required fewer corn heat units from planting to tasselling and silking and these variables were little affected by higher plant population densities relative to the conventional hybrids. In this case the former hybrids had more time for grain filling than the latter, which is an important characteristic for short-season areas. Leaf number above the ear was not affected by population density, however the LRS hybrid produced more leaves above the ear, which is the most important part of the plant canopy in terms of the contribution of assimilate to the grain. Leaf area index and percent light interception were increased with an increase of plant density and the LRS hybrid had higher average values than the NLRS hybrid and Pioneer 3979, and values only slightly lower than Pioneer 3902. Therefore, LRS hybrids may show promise for production in shorter-season areas with fewer corn heat units available, and where maize cultivation is not economical due to shortness of the growing season.

Table.5.1. Monthly mean temperature and total rainfall during the 1995 growing season and 30 year averages.

	1995		Averages *	
Month	Mean temperature (°C)	Rainfall (mm)	Mean temperature (°C)	Rainfall (mm)
May	12.6	81.1	13.1	70.6
June	20.6	73.0	18.1	88.3
July	22.1	152.6	21.1	89.7
August	20.7	139.0	19.8	92.6
September	13.7	86.2	14.7	97.9

* 30-yr averages

Table 5.2. Simple mean values of corn heat units from planting to tasselling (CHU-T), corn heat units from planting to silking (CHU-S), plant height (PH), ear height (EH), internode length above the ear (INT), leaf number above the ear (LN), leaf area index (LAI), and percent light interception (PLI) of four maize hybrids at location 1.

Populations (plants ha^{-1})	Hybrids	CHU-T	CHU-S	PH (cm)	EH (cm)	INT (cm)	LN	LAI	PLI (%)
50,000	LRS	1242.5	1355.4	132.0	41.6	11.6	7.8	2.6	77.4
	NLRS	1038.0	1143.3	91.7	27.9	12.9	4.9	1.9	70.7
	P3979	1363.6	1468.1	187.7	73.9	22.2	5.2	2.2	78.6
	P3902	1521.5	1632.1	205.3	83.4	20.6	5.9	2.7	78.9
100,000	LRS	1266.3	1392.4	136.7	45.6	11.6	7.8	3.0	86.8
	NLRS	1045.7	1153.3	96.0	31.3	12.9	5.0	2.5	82.1
	P3979	1408.8	1521.5	190.0	83.7	19.7	5.4	3.0	85.2
	P3902	1566.2	1689.4	216.0	95.9	20.6	5.8	3.4	87.5
150,000	LRS	1291.6	1431.9	138.4	50.3	11.7	7.6	4.0	94.1
	NLRS	1045.7	1195.4	104.0	34.2	14.2	4.9	2.9	88.3
	P3979	1431.9	1566.2	194.3	87.3	20.0	5.3	3.6	88.1
	P3902	1603.1	1745.8	219.7	97.1	20.9	5.9	4.1	91.3
200,000	LRS	1301.1	1441.1	141.3	53.5	11.7	7.5	4.1	94.3
	NLRS	1068.1	1203.3	109.7	40.3	13.9	5.0	3.4	90.9
	P3979	1468.1	1594.1	195.0	90.0	20.3	5.2	3.9	92.4
	P3902	1621.5	1765.6	222.0	98.4	21.2	5.9	4.2	92.3
C.V		1.4	1.2	1.3	3.2	4.5	5.2	13.0	2.1
LSD$_a$(0.05)		31.3	35.0	3.5	3.6	-	-	0.7	1.5
LSD$_b$(0.05)		36.9	41.5	4.5	3.6	1.3	0.5	0.7	3.0
Populations (P)		**	**	**	**	ns	ns	**	**
Hybrids (H)		**	**	**	**	**	**	**	**
P * H		*	**	**	**	*	ns	ns	ns

Abbreviations: LRS, leafy reduced-stature; NLRS, non-leafy reduced-stature; P3979, Pioneer (early check); P3902, Pioneer (medium check). LSD$_a$ is for comparing means within main plots while LSD$_b$ is for comparing means between main plots. *, Significant at the 0.05 level; ** significant at the 0.01 level; and ns, not significant.

Table 5.3. Simple mean values of corn heat units from planting to tasselling (CHU-T), corn heat units from planting to silking (CHU-S), plant height (PH), ear height (EH), internode length above the ear (INT), leaf number above the ear (LN), leaf area index (LAI), and percent light interception (PLI) of four maize hybrids at location 2

Populations (plants ha^{-1})	Hybrids	CHU-T	CHU-S	PH (cm)	EH (cm)	INT (cm)	LN	LAI	PLI (%)
50,000	LRS	1268.1	1377.2	123.0	33.0	12.0	7.5	1.9	63.7
	NLRS	1046.5	1164.3	77.3	22.8	11.5	4.8	1.4	54.4
	P3979	1405.7	1501.3	167.7	56.8	21.8	5.1	1.6	61.3
	P3902	1559.9	1664.4	172.7	62.6	18.6	6.0	2.0	64.5
100,000	LRS	1277.0	1386.3	141.0	36.6	13.2	7.9	2.5	65.1
	NLRS	1056.3	1171.3	88.0	27.1	12.4	4.9	2.2	62.0
	P3979	1436.6	1550.0	181.3	66.0	21.6	5.3	2.5	65.3
	P3902	1604.9	1719.3	184.0	67.3	20.0	5.8	2.7	74.1
150,000	LRS	1277.0	1426.8	143.0	38.0	13.5	7.8	2.8	78.6
	NLRS	1056.3	1214.5	90.0	33.0	11.6	4.9	2.4	63.6
	P3979	1464.6	1577.7	185.0	73.6	21.0	5.3	2.6	88.5
	P3902	1638.8	1766.7	193.7	74.7	19.8	6.0	3.0	78.9
200,000	LRS	1303.6	1473.1	143.7	40.1	13.4	7.8	3.3	83.3
	NLRS	1088.7	1223.2	96.3	35.2	13.1	4.7	2.7	73.1
	P3979	1501.3	1612.8	186.7	77.6	21.5	5.1	3.1	90.6
	P3902	1655.1	1782.6	197.7	77.6	21.1	5.8	3.4	89.9
C.V		1.6	1.7	1.6	3.3	7.4	5.5	10.1	9.3
LSD$_a$(0.05)		35.9	41.5	3.7	2.9	-	-	0.4	11.3
LSD$_b$(0.05)		39.4	44.5	3.9	3.3	2.0	0.5	0.5	14.5
Populations (P)		**	**	**	**	ns	ns	**	**
Hybrids (H)		**	**	**	**	**	**	**	**
P * H		ns	ns	**	**	ns	ns	ns	ns

Abbreviations: LRS, leafy reduced-stature; NLRS, non-leafy reduced-stature; P3979, Pioneer (early check); P3902, Pioneer (medium check). LSD$_a$ is for comparing means within main plots while LSD$_b$ is for comparing means between main plots. *, Significant at the 0.05 level; ** Significant at the 0.01 level; and ns, not significant.

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Chapter 6
GENERAL DISCUSSION

In general long-season maize hybrids are taller than short-season maize hybrids. The LRS and NLRS hybrids are shorter than conventional hybrids because they contain the reduced-stature gene rd1. Increased population density causes plant stems to become thinner and often taller (Gardner et al., 1985). Plant height and ear height were higher at higher population densities and this response to population density was more pronounced for the conventional hybrids than the reduced-stature hybrids.

Conventional maize hybrids had a greater leaf number above the ear than the NLRS hybrids. Among conventional hybrids, Cross and Zuber (1973) reported a significant positive relationship between plant height and number of leaves produced by maize hybrids. However, LRS hybrids had more leaves above the ear than the other types which was mainly due to the incorporation of the Leafy traits. Shaver (1983) indicated that the chief effect of the Leafy traits is to produce extra leaves above the ear in otherwise equivalent maize genotypes. There were no differences among population densities for leaf number above the ear, whereas leaf area index and percent light interception values increased as population density increased. In fact the increase of LAI and percent light interception at plant densities above 150,000 plants ha^{-1} was slight. Several investigations have reported decreased leaf area per plant, and increased LAI as plant density increased (Larson and Hanway, 1977).

Medium and long-season hybrids require more corn heat units from planting to tasselling, silking, and grain maturity than short-season maize hybrids. Corn heat units from planting to tasselling and corn heat units from planting to silking increased as population density increased. The increases in corn heat units to tasselling and silking were higher for conventional hybrids than the LRS and NLRS hybrids. As a result NLRS and LRS hybrids are more likely to be more tolerant of high population densities than the conventional hybrids.

Grain sink size is strongly associated with kernel number in grain crops, and kernel number is a function of plant dry matter accumulation (Fischer, 1985). Kernel row number was not affected by plant population density, however there were differences between hybrids in that Pioneer 3979 had fewer rows of kernels per ear than the other hybrids. Kernel number per row was affected by population density. All hybrids had more kernels per row at lower population densities, however as plant density increased the most affected hybrids were the conventional ones, indicating a greater tolerance of higher plant population densities by the LRS and NLRS hybrids. Similar results were reported for grain yield differences by shade intolerant hybrids, which produced more barren ears under shade than more shade tolerant hybrids (Stinson and Moss, 1960).

Ear diameter and ear length declined as population density increased with the conventional hybrids being most strongly affected. Tollenaar (1989) reported that recent hybrids maintain a constant harvest index as plant density increases because they are less prone to plant bareness at high density than older hybrids. Harvest index was not different among NLRS and the conventional hybrids, but the LRS hybrid had a higher harvest index values than the others.

LRS and NLRS hybrids had lower grain moisture contents than the conventional hybrids. As population density increased there was a sharp increase in the grain moisture contents for the conventional hybrids, which was probably due to increased shading. Maize hybrids differ in the rate at which moisture is lost from the grain during maturation (Cross and Caber, 1989). Most hybrids are physiologically mature at a grain moisture contents of about 30%, while the ideal moisture content for mechanical harvesting is about 25% (Oslon and Sander, 1988). Therefore, LRS and NLRS hybrids are more likely to achieve desirable grain moisture content in short-season environments even at higher population densities.

Single-plant grain yields were higher at low plant population densities and in paired rows than at higher densities in the same planting pattern for all hybrids. The paired row spacing with 56 cm between rows of adjacent pairs out yielded the normal row spacing (76 cm). Plants grown at a given plant population density usually yield more grain per unit land area when the distance between adjacent rows is decreased and the distance between plants within a row is increased (Prine, 1969). The single plant grain yields of the LRS and the NLRS hybrids were little affected by high population densities, while reductions in single plant grain yield were higher for the conventional hybrids. Based on the responses of LRS hybrids to a wide range of populations (50,000 to 200,000 plants ha $^{-1}$) and the responses to row spacing, the optimum population density for LRS hybrids may be even be higher than 110,000 to 130,000 indicated for plants grown in a conventional (76 cm) row spacing. This is mainly as a result of leafy and reduced-stature traits which combine to produce plants which performs well in narrower rows. Even though only one LRS hybrid was used in the broader population study, the results of population-row width study suggest that most LRS hybrids would respond to population level is in the same way.

Grain yield was highest for all hybrids at 100,000 plants ha^{-1}, in the second experiment. When we plotted the grain yield values of the LRS hybrid common to both experiments against all the six plant densities used in both experiments we have found that the grain yield of that LRS hybrid was higher at 130,000 than at 100,000 plants ha^{-1} at site 1, whereas at site 2 the reverse was true (Figure 6.1). The reductions in grain yield at 130,000 plants ha^{-1} at site 2 were probably a result of the hot and dry weather which occurred immediately after the planting of site two. Thus, plants at site one established under conditions of much better moisture availability than those at site two. The optimum plant density for LRS hybrids evaluated here lies between 110,000 and 120,000 plants ha^{-1} (Figure 6.1). Reductions in grain yield at higher population densities may have resulted from fewer flower initials being formed prior to flowering, poor pollination resulting from asynchrony of tasselling and silking, or from abortion of kernels after fertilization (Daynard and Muldon, 1983; Karlen and Camp, 1985; Hashemi-Dezfouli and Herbert, 1993). Duncan (1954) and Stringfield (1956) found that increasing plant population density to maximum levels resulted in higher yields with earlier maturing hybrids than later maturing hybrids. At lower plant densities

LRS and NLRS types generally produce more than one ear per plant (Modarres, 1995). However the conventional hybrids produce only one. Therefore hybrids which are able to produce more than one ear per plant (prolific) may be more density tolerant than hybrids with only one ear. Similar results were reported for prolific types by Russell (1968).

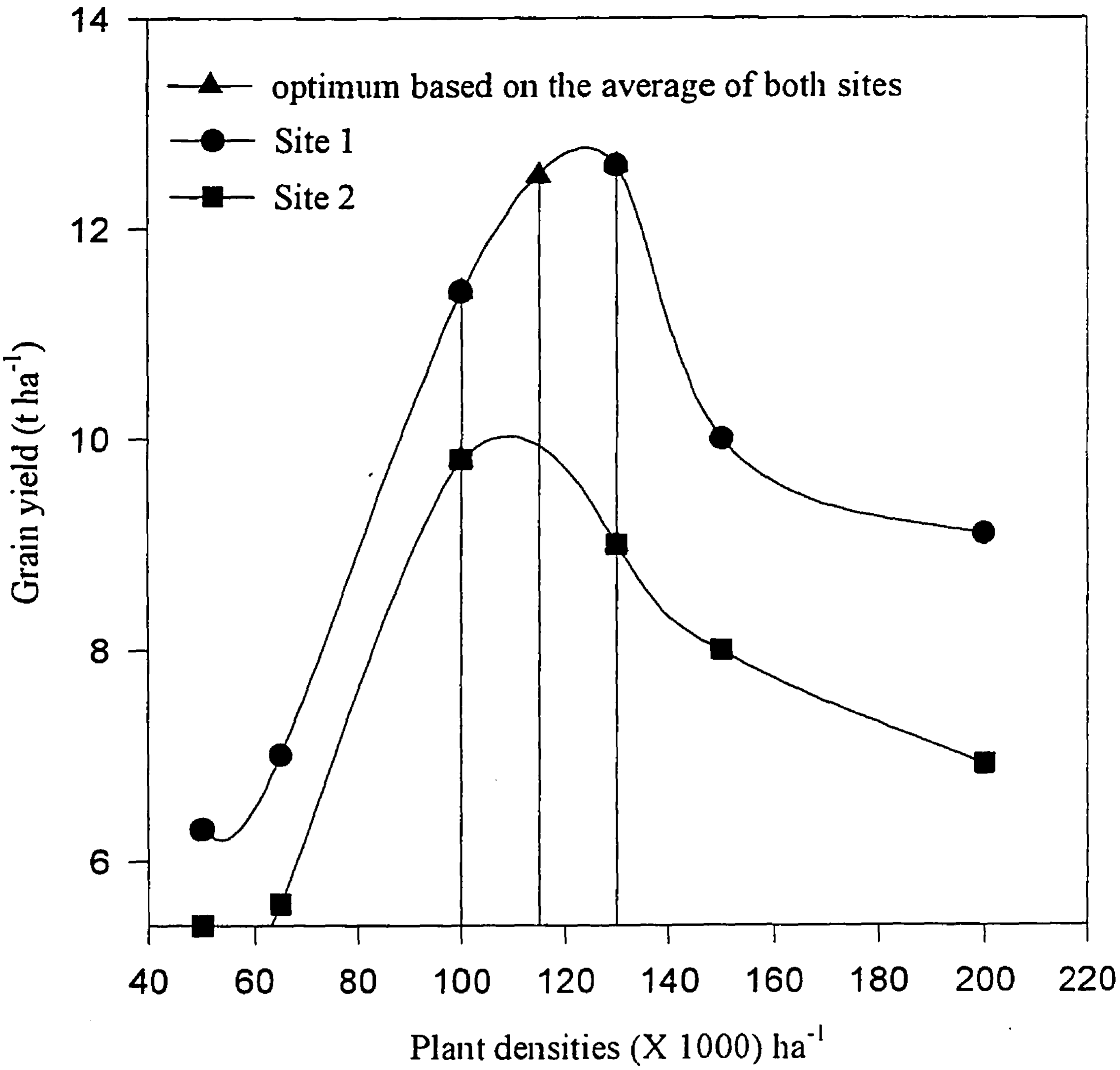


Fig. 6.1 The relationship between grain yield and plant density of a LRS maize hybrid.

Chapter 7

ACCEPTANCE OR REJECTION OF HYPOTHESES

In the experiments conducted here, the following hypotheses were accepted:

1. The optimum plant population density for the Leafy reduced-stature hybrids evaluated was higher than for the conventional hybrids evaluated
2. Leafy reduced-stature hybrids evaluated here were more tolerant of higher plant population densities, particularly those above the optimum levels for grain production than the conventional hybrids.
3. Leafy reduced-stature hybrids respond more (have greater yield increases) to narrower rows than do conventional hybrids.

Chapter 8

CONCLUSIONS

Based on the work reported in this thesis the following conclusions may be drawn.

1. At all plant population densities LRS hybrids produced more leaves above the ear than any of the other hybrids tested and as a result had better light interception than NLRS hybrids.
2. Leaf area index was higher for LRS than NLRS hybrids, and the value for LRS hybrid was comparable to the conventional hybrids.
3. LRS hybrids required fewer corn heat units for tasselling and silking and, as a result, had longer periods available for grain-filling than the conventional hybrids.
4. LRS and NLRS hybrids matured earlier than the conventional hybrids and as a result they are less likely to be have grain yield reductions due to late planting.
5. In general, grain yield of LRS hybrids increased until 120,000 plants ha^{-1} at site 1 and until 110,000 plants ha^{-1} at site 2. Therefore, LRS hybrids had the potential to produce more yield at higher population densities which should be useful for short-season areas.
6. Leafy reduced-stature hybrids had lower grain moisture contents, gave reasonable grain yields (particularly with paired rows and higher population densities) and tolerated high population densities better than the conventional hybrids. Therefore, LRS hybrids may show promise for maize production in short-season areas with fewer available corn heat units, and where maize cultivation is not currently economical.

Chapter 9

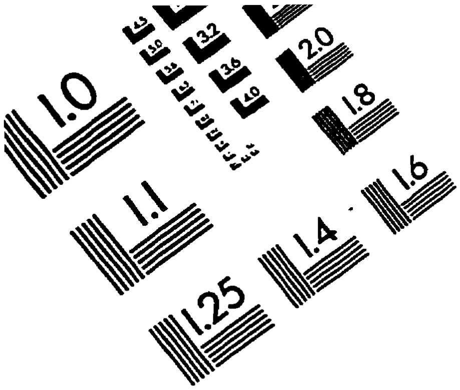
SUGGESTIONS FOR FUTURE STUDIES

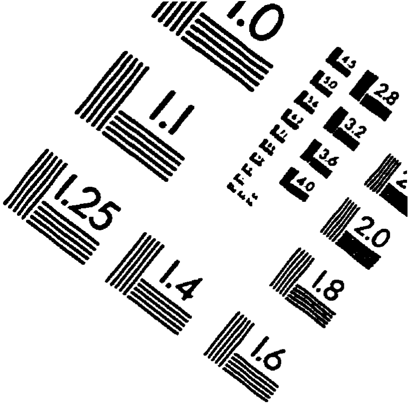
1. This study indicated that optimum plant density for an LRS hybrid was 115,000 plants ha^{-1}. However, to generalize this finding more hybrids of this type must be studied.

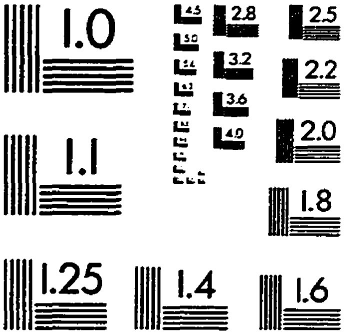
2. Fertilizer application rates were the same for all population densities, but we do not know how much fertilizer is needed at an optimum population density for LRS hybrids. This needs to be tested.

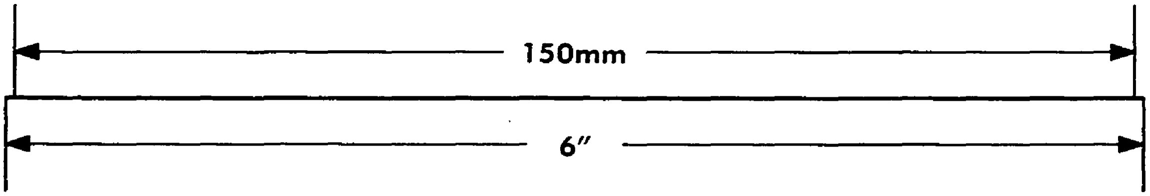
3. Visual observations indicated that LRS hybrids had lower lodging levels than the conventional hybrids, even under extremely high population densities (200,000 plants ha^{-1}). This might be a result of root system and stem strength for this type of plant. These two attributes of LRS hybrids should be investigated. Knowledge of them will be very important where population density is used as a technique to increase the yield of early maturity maize hybrids in a short-season areas.

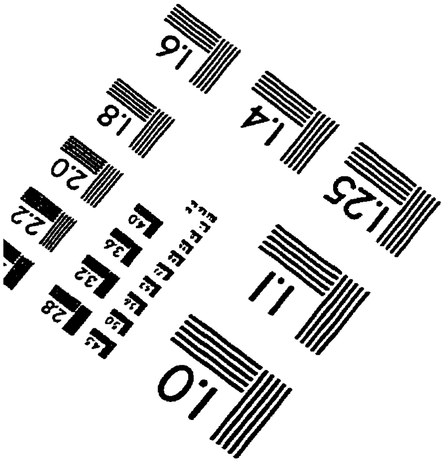
4. In order to broaden our understanding of LRS hybrids, studies involving a large number of LRS hybrids or near-isogenic pairs of hybrids should be conducted over a wide range of locations.

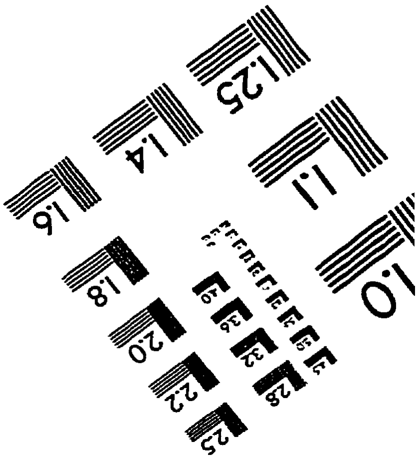












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