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Pinheiro, Maria Ermelinda Vaz Lourenco

STOVER FORAGE QUALITY AND STALK STRENGTH RELATIONSHIP IN CORN, ZEA MAYS L.

Iowa State University

PH.D. 1984

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Stover forage quality and stalk strength relationships in corn, *Zea mays* L.

by

Maria Ermelinda Vaz Lourenço Pinheiro

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

Department: Agronomy
Major: Crop Production and Physiology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1984

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INTRODUCTION

Lodging in corn has become a greater problem as farmers have increased the use of nitrogen fertilizer, increased plant densities, and used mechanical harvesting. Even though plant breeders have improved resistance to lodging, stalk lodging continues as a problem.

Plant breeders' contributions have been mostly on grain yield, but they have disregarded the effects that lodging resistance may have on forage quality. The aspect of forage quality of the stalk is becoming more important because corn silage and corn stalks are forages which help in reducing costs and maximizing profits. Corn silage is a major component of dairy and beef finishing rations, whereas corn stover is used extensively in beef cow forage systems.

Lodging of stalks is strongly related to two major factors: lower structural strength and disease-insect susceptibility. Since cell walls provide structural support for the plant, as well as possessing both the intrinsic and inducible factors affecting disease resistance, cell wall components are important factors involved in lodging resistance. But breeding for stalk strength could affect stover chemical composition and digestibility. Increased concentrations of lignin and cellulose have often been reported as directly associated with lodging resistance, which may decrease forage quality. Results obtained from other studies, however, have been contradictory. In addition to a greater concentration of total nonstructural carbohydrates (TNC), later maturity has also been reported as being associated with lodging resistance. Nonstructural components (mostly sugars), besides improving forage quality, might prolong the life of stalk tissues. This delays pith degeneration caused by disease agents, and helps to keep the stalks more turgid longer and thus increase stalk strength. Therefore, the relationship between stalk chemical composition and stalk strength is poorly understood.

It has been shown that improving stalk strength generally causes a decrease in grain yield. There are also reports that the presence of cytoplasmic male-sterility can increase both grain yield and forage dry matter yields of higher sugar concentration, especially under stress conditions such as high plant density, low soil moisture, and poor soil fertility.

The primary objectives of this study were (1) to evaluate the effect of stalk strength on stover quality and, in addition, other traits associated with stalk strength (rind thickness, sugar concentration in the sap, stalk moisture, and length, diameter, and volume of the internode); and (2) to relate stover dry matter yield and grain yield to stalk strength, male-sterility, and plant population.

LITERATURE REVIEW

The greater use of fertilizers, higher plant densities, and mechanical harvesting have increased the necessity of developing corn hybrids with greater resistance to stalk lodging. Plant breeders have made considerable progress in improving lodging resistance by selecting for greater crushing strength of the stalks, selecting for rind characteristics, increased stalk density, and resistance to stalk rotting diseases (Albrecht et al., 1983), without very much concern for the feeding value of the stover for ruminants. Yet, according to Tourbier and Rohweder (1983), trends during the last decade by dairy and livestock producers are to rely more heavily upon forages in their feeding programs because, by doing so, they are able to reduce feed costs and maximize profits.

In order to supply the ruminants with the energy needed, corn silage commonly is used. It has 18% more energy per unit of dry matter than alfalfa (haylage) or oat silage, which are the other two major forages used in midwestern U.S. (Rouse, 1978). The use of crop residues in forage systems for beef cows has also increased. Ward (1978) stated that beef cow producers in areas of corn and grain sorghum production have a valuable feed resource to provide nutrients for the non-lactating cows. For gestating cows, corn stalks may be deficient in protein and, for lactating cows, there may be a deficiency in both protein and energy. Besides, it usually is necessary to supplement certain minerals, particularly phosphorus, and vitamin A. Yet, the utilization of crop residues in forage systems for beef cows can lower feed costs and reduce the amount of land needed for alternative forage production such as silage or hay.

In this review, the major emphasis will be given to stalk strength, the relevant aspects of forage quality, and the agronomic and genetic factors which are related thereto.

Stalk Strength

Lodged plants of corn at harvest time increase both harvest losses and harvesting difficulties. Plants may lodge because of disease or insect susceptibility, poor mechanical strength of stem tissue, or interrelations of these or other factors. Lodging has been evaluated by counting lodged plants at harvest, but this is very much dependent upon environmental forces. Zuber and Grogan (1961) have introduced two quantitative measurements which can be obtained independently of the lodging environmental forces. The measurements are crushing strength and rind thickness. They found that, from the standpoint of economy and practicality, the use of the thickness of rind as an indication of stalk strength appeared to be more advantageous than measuring both thickness of rind and crushing strength. A more precise indication of stalk strength was obtained, however, by using both thickness of rind and crushing strength values.

Thompson (1963) reported that both crushing strength and rind thickness were significantly correlated with lodging. He concluded that crushing strength and rind thickness merit consideration as measures of stalk strength in a breeding program. Zuber (1973) stated that rind thickness may contribute up to 70% of the stalk strength in superior germplasm, with pith condition responsible for the remainder.

Cloninger et al. (1970) studied methods to evaluate stalk quality in corn. They reported that crushing strength, rind thickness, and weight of 5.1-cm sections together gave the best estimate of stalk quality among 15 possible single crosses of six inbred lines of known resistance or susceptibility to stalk lodging. Hunter and Dalbey (1937) reported that in "strong types" of corn stalks, the bundle sheaths surrounding vascular bundles were several cells thick. The subepidermal sclerenchyma layer also was thick. Magee (1948) reported a low bundle number per square millimeter in the rind, high percentage of sheath per bundle, large stalk diameter, and a wide band of lignified tissue extending inwardly from the epidermis. These were all associated with the strength of the stalk. Murdy (1960) stated that the tissue which strengthens and supports a maize stem can be subdivided into three categories: long fibers of the hypodermis, short fibers of peripheral bundle sheaths, and thickwalled lignified parenchyma. He also pointed out that bundles near the periphery of the stem are crowded, small, and generally provided with heavy sclerotic sheaths, whereas the more central ones are widely spaced, larger in size, and lack massive sheaths.

Mortimore and Ward (1964) reported that chemical analyses of corn plant tissues showed that high levels of soluble sugars in the pith at physiological maturity were associated with resistance to root and stalk rot. Treatments which increased resistance, namely, prevention of kernel development and low population densities, resulted in maintenance or increase of sugars in the pith.

Thompson (1964) stated that any internode below the ear would be satisfactory for determining crushing strength, rind thickness, internode diameter, and internode length. He pointed out that sampling should be confined to a specific internode for all plants, and that data should be obtained from more than one location for crushing strength and rind thickness. He reported that, on corn plants from the upper to the lower internodes, there was an increase in crushing strength, rind thickness, internode diameter, and there was a decrease in internode length.

Campbell (1964) suggested there are two means by which high concentrations of soluble solids in stalk juice may affect final stalk strength. Accumulated stalk sugars, by supplying the nutrients needed to prolong the life of stalk tissues in the fall, could delay the onset of structural degeneration caused by saprophytes and weak parasites. On the other hand, if stalk tissues die before the sugar reserves are exhausted, degeneration of stalk tissues by microorganisms may be accelerated. The net influence of soluble solids on final stalk strength would depend on the interaction of numerous factors characteristic of hybrid and season.

Esechie et al. (1977), in a study with sorghum for grain (Sorghum bicolor (L.) Moench), reported that lodging-resistant sorghums contained higher stalk TNC, larger diameters, and were generally later maturing. Their results indicated that resistance probably can be obtained without sacrificing yield. The higher TNC levels associated with late maturity and lodging resistance indicated that susceptible plants had transferred a larger portion of TNC from the stalk to the grain before the first killing frost. They concluded that several factors are directly associated with lodging resistance.

Cellulose and lignin contents in the basal internodes have been found to be associated with lodging resistance in small grains (Pinthus, 1973). Undersander et al. (1977) conducted a study with two synthetic corn populations that were selected for high and low crushing strength through five cycles of recurrent selection. The results indicated that even though two- to threefold differences existed in crushing strength between the high and low selections, the composition of the stalk changed only slightly. They found percentage values of lignin of 16.6 and 19.2 for the low and high crushing strength, respectively, for one of the synthetics. For the other synthetic, they found 15.6 and 17.6% lignin, respectively, for low and high stalk crushing strength. These values were not significantly different from stalk lignin percentages in the original unselected populations.

Albrecht et al. (1983) studied a synthetic variety (Iowa synthetic BS1) and six improved cycles of this population developed by recurrent selection for stalk strength or for resistance to *Diplodia* stalk rot (three cycles of selection for each trait). They reported that selection for stalk strength caused the yield of the synthetic variety to decrease from 113 to 78.7 bu $acre^{-1}$. Concentration of cell wall constituents decreased from 61.6% in the synthetic variety to 52.0% after three cycles of selection for stalk strength. Acid detergent fiber (ADF) of the whole internode sampled (second elongated internode) decreased from 42.4 to 35.3% after selection for stalk strength. Acid detergent lignin (ADL) concentration decreased from 5.7 to 4.2%. The concentration of TNC increased from 18.4% in the synthetic variety to 25.8% after selection for stalk strength. Simultaneously, *in vitro* dry matter disappearance (IVDMD) was also increased from 51.4 to 62.1%. After expressing fiber components as a percentage of dry matter from which TNC had been subtracted, they also reported lower values as strength increased. They concluded that forage quality of corn stalks was not reduced by selecting for stalk strength.

Thompson (1982) worked with two synthetics of corn that had undergone seven cycles of recurrent selection for lodging resistance. The material was evaluated for grain yield in crosses with two relatively unrelated testers. The combining statistical regression of grain yield on selection cycles indicated a yield reduction of 4% per cycle in tester crosses. He concluded that, even though there were significant yield reductions resulting from selection for lodging resistance, the reductions did not appear very detrimental because the reductions were minimized in hybrid combination with unrelated testers. He also stated that the improvement attained by lodging resistance in the synthetics studied should not seriously limit future progress in breeding for increased grain yield.

Davis and Crane (1976), using recurrent selection in increasing the stalk-rind thickness in a synthetic population of corn, reported that lodging decreased from 24.2 to 20.7% after two cycles of selection in topcrosses of the selected populations with five single crosses, and from 25.7 to 19.1% after three cycles of selection in the population *per se*.

They also reported a decrease in grain yield of 64.3 to 50.9 quintals ha^{-1} in the population per se and from 67.9 to 64.7 quintals ha^{-1} in the topcrosses with selection for rind thickness.

Colbert et al. (1984), in a study with five cycles of selection for high and low crushing strength of two synthetics (MoSQA and MoSQB), reported that selection for high crushing strength did not affect grain yield but significantly decreased stalk lodging. They also stated that stalk strength was positively correlated with flowering dates and soluble stalk solids. Greater yields due to selection for crushing strength were attributed in part to later maturity as reflected by the highly significant positive correlation between stalk crushing strength and flowering dates. Selection for greater crushing strength showed gradual increase in more vigorous plants that stayed green longer with little or no evidence of disease. On the other hand, among the selections for low crushing strength, plants died prematurely.

Forage Quality

The best estimate of production potential of a forage is the product of its voluntary intake by animals and its digestibility (Jorgensen and Howard, 1982). Both of these parameters can best be estimated by using feeding trials which are expensive and time consuming. But chemical analyses can provide information to provide reliable estimates of both intake and digestibility. Determination of neutral detergent fiber (NDF) allows the estimation of potential intake since it represents the amount of cell wall present in the feed. It is well known that by increasing the amount of cell wall constituents in the diet, dry matter intake (DMI) will be reduced. Van Soest and Robertson (1980) pointed out that cell wall content of the diet has a high correlation with forage intake of ruminants. The ADF values can be used to predict dry matter digestibility (Marten et al., 1975). Usually, percentages of ADF and ADL are means of estimating relative digestibility (Marten, 1980). Digestibility provides the best practical evaluation of the quality of a diet because it indicates the portion that can actually be used by the ruminant. The *in vitro* or artificial rumen technique has become the most commonly used procedure for estimating forage or diet sample digestibility (Holechek et al., 1982).

In general, quality of forages declines with maturity. Corn is an exception, however (Van Soest, 1982) due to the increasing dilution effect of the developing grain. Yet the stalk quality decreases after physiological maturity because of leaf loss (Tourbier and Rohweder, 1983).

Muller et al. (1971) evaluated three brown-midrib mutant genotypes of corn in inbred Tr background, bm1, bm3, and bm1/bm3. They found ADL values of 6.08, 5.13, 4.37, and

4.60% for the whole plant in normal, bm1, bm3, and bm1/bm3, respectively. These values were for plants harvested 35 days post-silking. The leaf blade, stem, and leaf sheath tissue of the three brown-midrib genotypes contained less ADL ($P<0.05$) than the normal corn.

Lechtenberg et al. (1972) studied the effect of brown-midrib mutants on the lignin percentage and IVDMD of corn stover. They found that stover harvested 55 days post-silking contained 8.15, 8.07, 4.96, and 8.81% ADL for genotypes bm1, bm2, bm3, and F2 normal, respectively. The IVDMD percentages were 49.3, 47.6, 56.3, and 46.2%, respectively. They emphasized that, since lignin limits the digestion and utilization of fibrous feeds by ruminants, the use of brown-midrib mutants for improving the forage quality of corn stover and silage appears promising.

Corn stalks are also utilized by grazing of the fields after harvesting the grain, by feeding after harvest and conservation for later use. Because of the stalks relatively low availability of metabolizable energy, the utilization is mainly as maintenance ratios for gestating cows when the energy requirement is less than during lactation (Ward, 1978). Dry matter digestibilities of 45 to 50% have been reported.

Wilkinson and Phipps (1979) studied the effect of genotype, plant density, and date of harvest on the composition of corn silage. They found that genotype and plant density (5.0, 9.8, and 13.5 plants m^{-2}) had relatively little effect on the composition of the silage or on IVDMD. For the whole-crop corn they reported values ranging from 21.7 to 23.3% for ADF and 1.52 to 1.85% for ADL. Digestible organic matter varied from 69.2 to 77.2%.

Struik (1982) studied four silage-maize hybrids sown on two dates. These hybrids differed in rate of grain filling and whole-crop digestibility. Apparent digestibility of the organic matter varied from 65.3 to 82.7% in the pith. For the rind, values ranging from 44.9 to 69.1% were found. The highest values were found in brown-midrib genotypes.

Plant Density

It is well known that grain and dry matter yields increase with increasing plant populations until a plateau is reached. Then, there is a decline at higher populations. The plant density at which the plateau occurs is a function of the amount of stress and genotype. Besides affecting yields, plant density also affects other plant characters like plant height, ear height, number of ears per plant, ear size and weight, and the silking to pollen shedding interval as pointed out by Wolf and Howard (1957), Colville and McGill (1962), Ortiz-Cereceras (1967), and El-Lakany and Russell

(1971). A trend for increased plant and ear height as plant density increases was reported by Zuber and Grogan (1956), Zuber et al. (1960), and Rutger and Crowder (1967). On the other hand, Dungan et al. (1958), Norden (1961), and Warren (1963) stated that the number of ears per plant, ear length, and weight decreased as plant density increased.

Increasing plant density affects date of silking according to Baracco (1961), Woolley et al. (1962), and Rossman and Cook (1966). They reported that the number of days between pollen shed and silk emergence was increased by 1 to 5 days as a result of a delay in silking due to increased plant density.

Colville et al. (1964) reported that the recommended rates of planting ranged from 29,652 to 59,304 plants ha^{-1} in humid areas and 14,826 to 29,652 plants ha^{-1} in nonirrigated semi-arid regions. Increasing the populations increased grain yields. Different genotypes and environments affect the response to increased population. Williams et al. (1968) studied corn at plant densities varying from 17,500 to 125,000 plants ha^{-1}, with nutrients and moisture nonlimiting. Grain yields fell off sharply at densities higher than 48,700 plants ha^{-1}. They found a close negative association between grain yield and sugar content of the stalk in the dent stage.

In studies with plant densities of 51,600 and 64,500 ha^{-1}, Troyer and Rosenbrook (1983) showed that higher density reduced yield from 76 to 73 quintals ha^{-1} and increased ranges among hybrids from 40 to 44 quintals ha^{-1}. Testing at above optimum plant densities increased barrenness, stalk breakage, and ear droppage. They also inferred that densities high enough to cause stress reduce yield because of both or either smaller ear size and barrenness. Also, stalk breakage and ear droppage increased because crowded corn plants have stems, shanks, and diameter much smaller due to mutual shading. Some hybrids are more tolerant than others to increasing plant populations. Schwanke (1965) showed that tolerant genotypes had reduced stalk barrenness and larger ear weights.

Prolific genotypes adjust to population pressure by varying the number of ears per plant with only slight ear weight changes (Collins et al., 1965). Thus, little or no whole plant barrenness under high populations results if extreme levels are tested (Bauman, 1959; Josephson, 1961; Hinkle and Garret, 1961).

Alexander et al. (1963) obtained a 47.9% increase in dry matter yields when increasing plant population from 16,000 to 33,000 plants ha^{-1}.

Bunting and Willey (1959) observed increased lodging at higher plant populations. The highest dry matter yields were obtained at the highest populations, but the contributions of the ear as a proportion of total dry matter was less. Bryant and Blaser (1968) showed that increasing plant populations from 39,000 to 98,000 plants ha^{-1} caused the silage yields to increase. Beyond 49,400 plants ha^{-1}, the increases were not significant. Rutger and Crowder (1967) reported an increase of 6% in total dry matter yield as the plant population was increased from 50,000 to 88,000 plants ha^{-1}. Maturity was delayed as plant populations increased and the amount of dry shelled grain in the silage decreased at the higher populations.

Alessi and Power (1974) reported that dry matter yields increased with populations up to 60,000 plants ha^{-1} before declining. Grain yields also were increased, but declined at 50,000 plants ha^{-1}.

Hoeffliger (1980) investigated the effects of plant populations, hybrids, and date of harvest on dry matter yields and nutritive value of corn for silage in northeast Iowa. The plant densities used were 54,300, 64,200, and 74,100 plants ha^{-1} in 1978 and 54,300, 69,100, and 84,000 plants ha^{-1} in 1979. From a population of 54,300 to 84,000 plants ha^{-1}, both dry matter yield of ears and percentage of ears declined. No statistically significant effect of population on dry matter yield was evident in 1978. Also, yield of nutrients was unaffected by varying populations, and plant population effects on percentage IVDMD as well as percentage crude protein were negligible in both years.

Tourbier and Rohweder (1983) studied plant populations above 66,717 plants ha^{-1} and reported increased silage yields which were not statistically significant. At plant populations of 46,949 and 96,369 plants ha^{-1} at optimum fertility, average silage yields of 12.6 and 15.7 metric tons ha^{-1} were produced. They reported that increasing plant populations from 46,949 to 96,369 plants ha^{-1} did not change significantly or practically the concentration of grain, crude protein, ADF, ADL, and IVDMD. They also suggested that, if an increased population results in a lower grain concentration, increased fiber, or increased nitrate concentration in the silage, digestibility or intake could be adversely affected.

Male Sterility

Cytoplasmic male-sterility is a trait expressed by plants carrying a particular type of cytoplasm, which can be attributed to the DNA that is found in organeles such as chloroplasts and mitochondria (Flavell, 1974; Barratt and Peterson, 1977). These plants show little or no pollen production but will produce seed if pollinators are present. In case no restorer gene is present in the nucleus of pollinators, the offspring will also be male-sterile, since the cytoplasm is derived entirely from female gameta, and likewise for the next generation (Levings and Pring, 1976;

Fleming, 1975). The transfer of a particular genotype to the male-sterility producing cytoplasm can occur automatically if any specified genotype is used continuously as a pollinator (Allard, 1960). Therefore, the maintenance and transfer of male sterility is straightforward.

Rogers and Edwardson (1952) made cytological studies and showed the differences among normal, partially sterile, and sterile plants (tassels and pollen). They suggested that it might be concluded that the male-sterile condition results in part from the failure of starch production in the pollen grain during the period immediately following meiosis. They also stated that experimental data suggest that the male-sterile character has a differential effect on yield in the presence of different genotypes.

Duvick (1958) determined that substitution of Texas for normal cytoplasm changed the performance pattern of some of the hybrids with respect to grain yield, barrenness, tillering, and root lodging. The extent and direction of the changes were affected by genotype and physical environment during the growing season. No consistent differences between normal and cytoplasmically sterile forms were found relative to stalk breakage, leaf blight, or moisture percentage of the grain.

Chinwuba et al. (1961) reported that silage from male-sterile crosses outyielded their fertile counterparts, especially at high plant populations. And male-sterile single crosses reacted similarly to the detasseled fertile single crosses at different populations. Meyer (1970) reported that at high plant densities of 30,000 to 36,000 plants $acre^{-1}$, Texas cytoplasmic male-sterile hybrids tended to increase grain yield slightly over that of the normal population, whereas grain yield of the normal hybrids decreased substantially. Therefore, the presence of male sterility enhanced the hybrid tolerance to increased population. He observed less barrenness, faster silking rates, smaller kernel weight, smaller leaf area index, higher leaf efficiency, shorter plant height, and more lodging. He suggested that the response of cytoplasmic male-sterility might be associated with a reduced competition for both or either available photosynthates and nutrients between the ear primordia and the dominant tassel. In a study conducted by Bruce et al. (1966) with a male-sterile hybrid and its fertile counterpart, it was found that the male-sterile strain consistently yielded more grain than its fertile counterpart, especially because of the greater number of second ears produced. Under reduced levels of nitrogen (N) and soil water, the ear diameter and length were more reduced with the fertile strain. Other studies also indicated that the presence of male sterility in corn can increase grain yields compared to its fertile counterparts, particularly under stress conditions such as high plant populations, moisture deficits, and low soil productivity (Buren, 1970; Grogan et al., 1965; Meyer, 1970; Sanford et al., 1965).

The male-sterile tassel saves the plant energy and nutrients normally used for pollen production (Rogers and Edwardson, 1952; Grogan, 1956; Sanford et al., 1965). Also, less indoleacetic acid is produced by the male-sterile tassel which decreases the rate of stalk growth and sucrose accumulation and thereby reduces competition between stalk and ear prior to silking (Anderson, 1967; Enyinnaya, 1980; Criswell et al., 1974; Sarvella and Grogan, 1976). Finally, it has been suggested that greater tolerance to drought conditions could also be accounted for by greater root development and, consequently, greater ability to absorb water, since low auxin levels stimulate root growth (Vincent and Woolley, 1972).

Male sterility in corn thus has an economic potential in reducing the detrimental effect of stress conditions. Growing fields with blends of predominantly male-sterile plants but with some fertile plants can increase grain yield and total biomass production (Enyinnaya, 1980; Sanford et al., 1965).

Texas male-sterile cytoplasm was the first source to be used extensively in the U.S.A. and Canada, before the epiphytotic of southern leaf blight, Helminthosporium maydis race T, in 1970. Gracen and Grogan (1974) studied the epiphytotic of this fungi on Texas male-sterile cytoplasm and pointed out the problem that might occur if using a uniform cytoplasm for hybrid corn production. Since this kind of male-sterile cytoplasm is especially susceptible to the disease (Hooker et al., 1970; Scheifele, 1970; Scheifele et al., 1970; Smith et al., 1971; Tatum, 1971; Noble, 1973; Lim et al., 1974), new sources of male-sterile cytoplasm (Cms and Sms) resistant to corn leaf blight were developed and made available to corn seed producers.

Also, there has been interest in the use of nonfertilized, male-sterile corn for silage because of its high sugar content of the stalk. No studies have been reported, however, where pollinators were used to obtain normal grain yields in addition to greater tonnage yield of silage at high populations.

In the U.S.A., the importance of presence of grain in order to reach high yields has been emphasized by Moss (1962). He pointed out that one month after flowering, barren maize plants had a photosynthetic rate much lower than that of normal plants. He concluded that lower yields of fodder dry matter should be expected from barren plants of male-sterile cultivars with high sugar than from counterparts with grain.

Marten and Westerberg (1972) produced fodder from a male-sterile and a normal cultivar by procedures causing both barren and fruited plants of both cultivars. Plants with grain yielded 20% more dry matter than barren plants of both cultivars (male-sterile and normal) and were greater in digestible dry matter (27% compared to 22% for barren plants). They reported IVDMD values of 68.4 and 62.0% for the stover of the male-sterile barren and fruited, respectively. For the normal barren and fruited the values were 66.9 and 56.7%, respectively. Dry matter yields were 16.8 and 14.0 tons ha^{-1} for the male-sterile fruited and barren, respectively, and 15.4 and 12.8 tons ha^{-1} for the normal fruited and barren, respectively. They concluded that yield and quality of silage are likely to increase by developing normal, fruited genotypes instead of male-sterile, high sugar genotypes.

Studies in northwest Europe have shown that the presence of grain for total dry matter production and forage quality is not as important as in the U.S.A. or in tropical or subtropical regions. Bunting (1976) discussed post-flowering trends on yield and quality factors as measured separately in the stem, leaf, husk, and ear components. The shoot dry weight of the fertile plants was 6% greater than that of the sterile without ears. To evaluate forage quality in England, Bunting (1975) conducted four experiments. He compared isogenic sterile and fertile plants of corn grown for silage. He found that the absence of grain had little effect on concentration of nitrogen, ash, and IVDMD, but increased the content of pepsin soluble material and hot water soluble carbohydrates. The results suggested that high grain content is not an essential requirement for yield and quality in forage corn grown in northern European countries.

Daynard et al. (1980) stated that grain yield of hybrids adapted to northern environments tends to be restricted by a "source" limitation (which is the opposite of what is observed in U.S.A.) caused by earliness of flowering, by the resulting small leaf surface per plant, and by the rapidity of grain dry weight accumulation which may cause leaves to senesce early. Also, the temperatures in northern areas are cooler and favor forage quality. In the U.S.A. and tropical or subtropical areas, temperatures are higher, causing photosynthetic products to be more rapidly converted to structural components, and enhancing enzymatic activities associated with lignin biosynthesis (Van Soest, 1982).

Even though the presence of grain seems to be much more important for total biomass production in the U.S.A. than in northern environments, studies on forage quality are not so clear-cut and sometimes have been contradictory. Bratzler et al. (1965) stated that barren, high-sugar corn was somewhat lower in digestibility to sheep than was silage from some cultivars pollinated to form grain.

Cummins and McCullough (1971) compared male-sterile and male-fertile corn for dry matter production, total available carbohydrates, silage digestibility, and volatile fatty acid production from silage during rumen fermentation. They concluded that, at the maturity studied, male-sterile corn plants (without kernel development) were comparable to male-fertile corn plants (with kernel development) for making silage. Perry and Caldwell (1969) compared the yield and quality of a high-sugar male-sterile hybrid corn (without grain) with a typical starchy dent corn. Under equal rates of seeding (56,800 seeds ha^{-1}), high-sugar corn yielded 6,626 and starchy dent corn yielded 14,025 kg ha^{-1} of silage dry matter. The digestibility of male-sterile corn silage was significantly greater than that made from regular starchy corn.

Stake et al. (1973) compared nutritive qualities of high-sugar, male-sterile hybrid corn and regular, dent-hybrid corn silages. They reported 8.59 and 6.34% crude protein, respectively, for high-sugar and regular corn silage. Dry matter yields per hectare were greater for regular corn in the first year but not in the second year of the study. Apparent digestibilities of protein and fiber were greater for the high-sugar corn silage: 63.5 versus 52.2% and 61.9 versus 59.3%, respectively.

MATERIALS AND METHODS

Experimental Procedure

The study was conducted in 1983. Field experiments were located at the Iowa State University Agronomy and Agricultural Engineering Research Center, Boone County (near Ames), Iowa (L1) and Northeast Iowa Research Center, Nashua, Iowa (L2).

At the Agronomy Research Center, the soil was a Nicollet silt loam (Aquic Hapludoll, fine-loamy, mixed, mesic). Nitrogen was applied as urea in the spring at the rate of 168 kg ha^{-1} (150 lb $acre^{-1}$) and the herbicide used was Lasso (alachlor) applied as a pre-emergence herbicide.

At the Northeast Iowa Research Center, the soil was a Floyd loam (Aquic Hapludoll, fine-loamy, mixed, mesic). In the fall of 1982, P_2O_5 and K_2O were applied at the rate of 135 kg ha^{-1} (120 lb $acre^{-1}$) each. In the spring, 168 kg ha^{-1} of N was applied as urea. Weeds were controlled using a mixture of Lasso (alachlor) and Bladex (cyanazine).

The experimental design was a split-split plot with three replications. Three different plant densities were established as the whole plots, seven hybrids composed the subplots, and two harvests composed the sub-subplots. The experimental unit consisted of four rows, spaced 76 cm between rows and 9.90 m long. The two harvests were made, the first at mid-silk (T1) of the latest hybrid, and the second at physiological maturity (T2). The two middle rows in each subplot were used for obtaining the data.

Experiments were planted on 3 June (L1) and on 31 May (L2). The plant populations were 32,123, 64,246, and 96,369 plants hectare^{-1} designated, respectively, as P1, P2, and P3.

The hybrids used were:

Hybrid		Pedigree	Source of seed
MSC,	male-sterile Cms cytoplasm with ears covered	TW729xTW473	Acco Seeds Belmond, Iowa
C3,	third cycle of selection for stalk strength of Iowa synthetic BS1	BS1C_3	Dr. W. A. Russell ISU, Ames
C1,	first cycle of selection for stalk strength of Iowa synthetic BS1	BS1C1	Dr. W. A. Russell ISU, Ames
C0,	synthetic variety	BS1C0	Dr. W. A. Russell ISU, Ames
N,	normal cytoplasm	TW129xTW473	Acco Seed Belmond, Iowa
MS,	male-sterile Cms cytoplasm	TW729xTW473	Acco Seed Belmond, Iowa
PR,	prolific	Q66-7xQ67-9	Dr. A. R. Hallauer ISU, Ames

Plant material used as C0, C1, and C3 has been described by Martin and Russell (1984). The ears of five plants for each of the middle rows of MSC plots were covered before silking to avoid pollination.

The first harvest was made at mid-silking, and the second was taken at physiological maturity. Actual first harvest dates were 27 June for Ames and 3 July for Nashua. Second harvest dates were 1 October for Ames and 8 October for Nashua.

At each harvest, eight consecutive plants of one of the middle rows were evaluated for stalk strength by using a machine and method first described by Durrell (1925), but later modified by Jenkins (1930) and Jenkins and Gaessler (1934). Each stalk was placed in the machine, which is designed to apply a measured increasing lateral force until the stalk breaks. All stalks were tested at the second elongated internode, with force applied in the middle on the minor diameter. On the same internode, length and both diameters were also measured. Portions of the stalks comprising the second elongated internode and one-half of each adjacent internode were cut and split in halves. One-half was weighed and dried at 60°C for further stalk quality analyses after being ground to pass a 1-mm screen. The other half was frozen and further utilized for sugar, rind, and pith analyses. Rind and pith were separated after thawing by scraping the pith from the rind with a spatula. After measuring the rind thickness, pith and rind were also prepared like the stalk halves for further quality evaluation. Rind thickness was measured with a Lukfin chrome-clad micrometer. The percentage of sugar in the sap, after being squeezed from the pith, was estimated using a Bausch and Lomb light refractometer that measured the index of refraction of the sap solution placed on the glass prism.

In addition to the variables determined in the first harvest, grain yield and stover yield were also evaluated for the second harvest. At Nashua, the stover yield of the male-sterile hybrid with ears covered was not determined. Therefore, the data collected in the study were as follows:

SS	Stalk strength
SSS	Stalk strength per unit of sectional area of the stalk
RTH	Rind thickness
SU	Sugar concentration in the sap
SM	Stalk moisture for the first harvest
LH	Internode length
D	Internode mean diameter
V	Internode volume
ADF-S	Acid detergent fiber of the whole internode
ADF-SS	Acid detergent fiber of the whole internode adjusted
ADF-R	Acid detergent fiber of the rind
ADF-P	Acid detergent fiber of the pith
ADL-S	Acid detergent lignin of the whole internode
ADL-SS	Acid detergent lignin of the whole internode adjusted
ADL-R	Acid detergent lignin of the rind
ADL-P	Acid detergent lignin of the pith
IVDMD-S	*In vitro* dry matter disappearance of the whole internode
IVDMD-R	*In vitro* dry matter disappearance of the rind
IVDMD-P	*In vitro* dry matter disappearance of the pith
IVDMD-ST	*In vitro* dry matter disappearance of the stover
	Grain yield
	Stover dry matter yield

The IVDMD was determined via a direct acidification, two stage procedure (Marten and Barnes, 1980). The ADL and ADF were determined by the methods of Goering and Van Soest (1970), with procedural modifications as proposed by Van Soest and Robertson (1980). Grain yield was evaluated in the two middle rows of each plot. Stover yield was determined after picking the ears in 2.10 m of one of the middle rows. After being chopped, subsamples of stover, as well as of the ears, were taken for dry matter determinations. Subsamples were placed in nylon net bags and dried at 65^{o}C to a constant weight in a forced-air drier.

Acid detergent fiber and ADL adjusted were calculated by expressing ADF and ADL on percentage dry matter from which sugars were subtracted.

Statistical Analyses

All the variables except stalk moisture, ADF of the stalk adjusted, and ADL of the stalk adjusted were analyzed as a split-split plot at two locations with plant populations as whole plots, hybrids as subplots, and harvests as sub-subplots. Stalk moisture, ADF, and ADL of the stalk after being adjusted for sugar concentration in the stalk were analyzed as a split plot at two locations with populations as whole plots and hybrids as subplots, since the data refer just to the first harvest. This same model was also used for grain yield, stover yield, and IVDMD of the stover because these variables were obtained only for the second harvest.

Partial correlation coefficients were determined between most of the variables in order to select those most correlated with stalk strength. Regression analysis was used to find a model to explain stalk strength. The means for the significant main effects and treatment combinations were compared by the LSD (least significant difference) according to Snedecor and Cochran (1975). The Statistical Analyses System (SAS) was used for data analyses (Service, 1972).

Climatological Data

Rainfall and temperature data were taken at the Agronomy and Agricultural Engineering Research Center and at the Northeast Iowa Research Center, Nashua (Appendix Tables A1 and A2, respectively).

The 1983 season had weather extremes, both of rainfall and temperature. Even though the spring was wet, the corn plants suffered some moisture stress in July and August, especially at Nashua. Temperature stress occurred at both locations for periods in July and August.

RESULTS

Analyses of variance for variables measured at both locations are summarized in Tables 1 to 3. The results of the analyses of variance for data obtained from both harvests are presented in Table 1. The analyses of variance for the variables grain yield, stover yield, and IVDMD of the stover (obtained only from the second harvest) are shown in Table 2. Table 3 summarizes the results of the analyses of variance for variables such as stalk moisture, ADF, and ADL of the stalk expressed on a dry matter basis from which sugars were subtracted.

Stalk Strength

Plant population, hybrid, and harvest time had a highly significant effect ($p<0.01$) on stalk strength. The first-order interaction of plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time were also highly significant. The effect of location x hybrid and plant population x hybrid x harvest time were significant but just at $p\leq 0.05$. The effect of the other interactions was not significant.

The overall means for plant population levels (Table 4) indicate that stalk strength decreased significantly with increasing plant population levels, although it was not observed with all the hybrids. For the first and third cycles of

Table 1. Mean squares and significance in the analyses of variance

Source	df	Variables		
		Length	Diameter	Volume
Location (L)	1	26.16	0.19	2080.75
Error (a)	4	4.18	0.13	686.37
Plant population (P)	2	0.11	8.18**	23501.92**
L x P	2	1.69	0.03	43.09
Error (b)	8	4.02	0.02	136.10
Hybrid (H)	6	28.14**	0.47**	3823.74**
P x H	12	3.87**	0.05	202.45
L x H	6	0.47	0.01	49.31
L x P x H	12	1.33	0.01	99.72
Error (c)	72	1.42	0.03	124.65
Harvest time (T)	1	47.99**	0.00	679.55**
L x T	1	30.39**	0.01	346.84**
P x T	2	0.40	0.03	35.20
H x T	6	0.72	0.01	25.83
L x P x T	2	1.16	0.01	109.55
L x H x T	6	0.27	0.11	51.98
P x H x T	12	0.35	0.01	52.02
Residual	96	0.79	0.01	41.99

*,**Significant at $p<0.05$ and $p<0.01$, respectively, in this table and all subsequent tables.

Variables					
ADF-S	ADL-S	ADF-R	ADL-R	ADF-P	ADL-P
470.32*	39.89*	26.80	0.17	102.76	0.17
56.53	3.35	48.68	10.37	17.98	0.20
568.02**	12.97**	408.73**	8.48*	574.13**	1.67
12.31	0.67	27.39	0.58	24.22	0.31
23.34	1.29	16.94	1.37	37.40	0.44
658.40**	23.59**	425.15**	20.00**	738.86**	4.29**
40.54**	2.37**	25.12**	3.91*	50.08**	0.56*
21.83	0.41	10.26	0.17	16.20	0.45
16.53	1.04	11.95	2.25	15.43	0.19
12.17	0.79	8.41	1.62	14.76	0.26
858.22**	30.78**	686.27**	22.10**	1677.52**	17.55**
209.68**	16.50**	25.65*	0.00	281.28**	3.32**
82.59**	2.92**	55.51**	3.59*	76.60**	0.32
74.61**	2.04**	23.46**	3.97**	76.07**	1.11**
20.65	1.02	3.18	3.20	6.65	0.08
12.00	0.75	8.54	0.84	9.92	0.17
13.52	0.99	3.41	0.67	10.45	0.24
8.48	0.52	6.49	1.05	11.35	0.22

Table 1. (Continued)

Source	df	Variables		
		IVDMD-S	IVDMD-R	IVDMD-P
Location (L)	1	532.85*	3.75	12.63
Error (a)	4	46.81	53.76	23.97
Plant population (P)	2	923.82**	828.93**	612.50**
L x P	2	28.98	45.29	34.22
Error (b)	8	45.07	33.46	55.30
Hybrid (H)	6	1084.44**	722.91**	1026.20**
P x H	12	77.33**	62.42**	93.95**
L x H	6	18.12	14.37	28.85
L x P x H	12	21.86	18.08	22.97
Error (c)	72	17.58	15.36	24.12
Harvest time (T)	1	1089.58**	1199.92**	1849.08**
L x T	1	264.84**	184.10**	193.71**
P x T	2	140.58**	75.35**	97.31**
H x T	6	91.42**	59.67**	84.94**
L x P x T	2	8.91	3.15	15.76
L x H x T	6	11.73	19.17	18.66
P x H x T	12	18.19	3.93	18.57
Residual	96	12.53	8.74	10.78

Variables			
Stalk strength	SSS	RTH	Sugar
57.44	1.29	0.43	34.65
35.81	4.52	0.06	7.07
14845.46**	63.79**	5.17**	59.10**
27.88	2.66	0.05	3.64
46.48	1.70	0.04	1.34
3773.06**	149.65**	0.99**	161.46**
334.92**	7.73**	0.08**	8.49**
69.74*	2.11	0.03	1.63
20.20	1.55	0.03	3.48
28.63	1.49	0.02	2.38
1642.29**	56.85**	0.84**	3.24
742.84**	32.03**	0.62**	44.10**
540.74**	8.83**	0.08	7.44*
299.70**	10.26**	0.04	11.33**
4.77	0.23	0.01	6.22
17.23	0.80	0.01	2.04
52.75*	0.82	0.03	1.57
25.16	0.86	0.03	2.38

Table 2. Mean squares and significance in the analyses of variance for the second harvest

		Variable		Variables	
Source	df	Grain yield	df	Stover yield	IVDMD-ST
Location (L)	1	965.66*	1	226.26	6.22
Error (a)	4	79.47	4	70.83	4.46
Plant pop.	2	6040.82**	2	54.10**	110.84**
L x P	2	49.76	2	10.63	12.19
Error (b)	8	60.22	8	5.79	8.50
Hybrid (H)	5	2336.46**	6	167.41**	196.80**
P x H	10	181.61**	12	7.11	19.63**
L x H	5	8.09	5	0.00	19.52*
L x P x H	10	68.36	10	4.52	16.25*
Residual	60	52.80	66	8.23	7.34

Table 3. Mean squares and significance in the analyses of variance for the first harvest

		Variables		
Source	df	Stalk moisture	ADF-SS	ADL-SS
Location (L)	1	31.56*	164.86	55.87*
Error (a)	4	3.23	34.66	2.69
Plant pop. (P)	2	5.03**	29.29	0.43
L x P	2	4.81	59.22	0.76
Error (b)	8	0.55	39.74	2.47
Hybrid (H)	6	88.02**	267.21**	14.88**
P x H	12	6.14**	62.95	2.35
L x H	6	1.29	21.65	0.91
L x P x H	12	1.70	25.36	1.61
Residual	72	1.62	55.59	1.64

Table 4. Stalk strength as affected by hybrid and plant population levels[a]

Plant pop.	Hybrid MSC	C3	C1	C0	N	MS	PR	Mean
	kg							
P1	80.1	50.5	40.0	35.8	54.7	57.9	37.6	51.0
P2	52.4	28.6	26.5	23.2	35.0	33.1	27.4	32.3
P3	36.9	25.5	22.1	17.1	24.9	26.0	24.1	25.2
Mean	56.5	34.9	29.5	25.3	38.2	39.0	29.7	

[a]$LSD_{0.05}$ for plant population = 2.43; for hybrid = 2.51; for plant population at same or different hybrid = 4.92

selection hybrids and for the prolific, there was no significant difference between stalk strength at the highest and intermediate plant population levels (Figure 1).

The overall means for each harvest (Table 5) indicate that corn stalks were weaker at physiological maturity (T2) than at mid-silking (T1). For the male-sterile with ears covered, however, the stalk strength increased with maturity, and the synthetic variety was not affected significantly by time of harvest.

Stalk strength decreased significantly with time at both locations, but this was more evident at Ames (Table 6). At the highest and lowest plant densities (P3 and P1), stalk strength did not decrease significantly with time.

Figure 1. Stalk strength as affected by plant population and hybrids

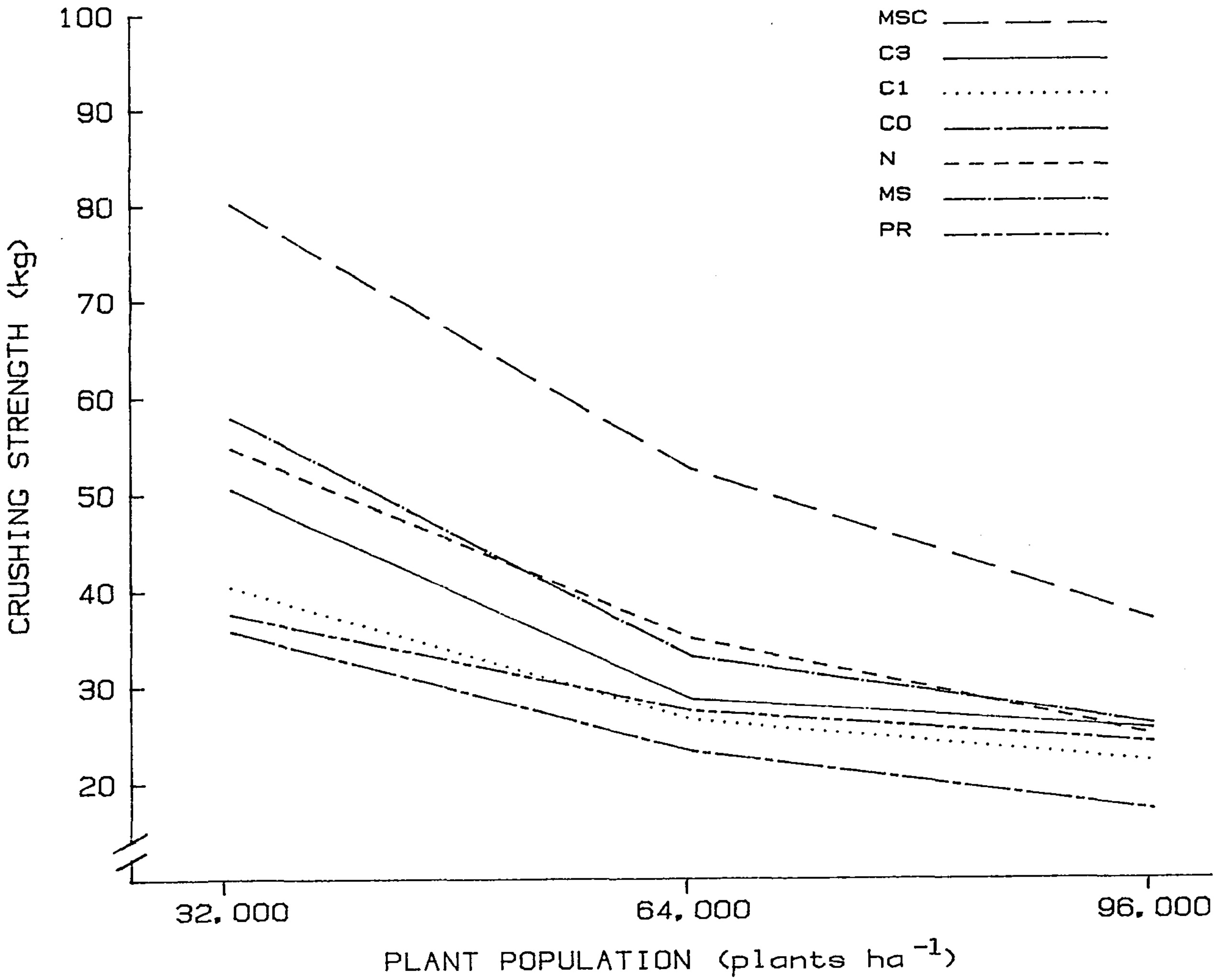

MSC
C3
C1
CO
N
MS
PR
100
90
80
70
60
50
40
30
20
CRUSHING STRENGTH (kg)
32,000
64,000
96,000
PLANT POPULATION (plants ha $^{-1}$)

Table 5. Stalk strength as affected by hybrid and harvest time[a]

Harvest time	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	kg							
T1	54.6	37.0	30.8	25.9	42.9	45.3	34.7	38.7
T2	58.3	32.8	28.2	24.8	33.6	32.7	24.8	33.6

[a]$LSD_{0.05}$ for harvest time = 1.25; for harvest time at same hybrid = 2.17.

Table 6. Stalk strength as affected by harvest time, location, and population[a]

Harvest time	Location		Plant population		
	L1	L2	P1	P2	P3
	kg				
T1	40.0	37.5	56.1	34.7	25.3
T2	31.4	35.8	45.8	29.9	25.1

[a]$LSD_{0.05}$ for harvest time at same location = 1.77; for harvest time at same plant population = 2.17.

Stalk strength per unit of stalk area was also evaluated. Plant population, hybrid, and harvest time had a highly significant effect on stalk strength per unit of area. The first-order interactions plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time also had a highly significant effect (Table 1).

The overall means for plant population (Table 7) indicate that stalk strength for unit of sectional area decreased significantly with increasing plant populations. Although the effect of the plant population x hybrid interaction was highly significant, examining each hybrid by plant population indicated that stalk strength per unit of area did not decrease significantly from P2 to P3 except in the male-sterile hybrid with

Table 7. Stalk strength per unit of area as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	$kg\ cm^{-2}$							
P1	13.2	9.6	6.7	6.2	9.0	9.3	5.0	8.4
P2	11.6	7.1	6.1	5.5	7.6	7.5	5.2	7.4
P3	9.2	6.9	5.7	5.6	7.2	7.1	5.5	6.7
Mean	11.3	7.9	6.2	5.8	7.9	7.9	5.2	

[a]$LSD_{0.05}$ for plant population = 0.46; for hybrid = 0.57; for plant population at same or different hybrid = 1.09.

ears covered. The first cycle of selection hybrid was not affected by plant density.

The overall hybrid means indicate that male-sterile hybrid with ears covered was the strongest, followed by the male sterile, normal, and third cycle of selection for stalk strength. The last three were not significantly different. The first cycle of selection hybrid and the prolific were similar and had higher stalk strength than the synthetic variety which was the weakest. This was observed on a stalk strength basis (Table 4), but on a stalk strength per unit area basis (Table 7), the weakest was the prolific hybrid. The plant population by hybrid means show that the male-sterile hybrid with ears covered was the strongest and that the prolific was one of the weakest at all plant population levels.

In general, stalk strength per unit of area decreased from the first to the second harvest except for the male-sterile hybrid with ears covered which actually increased significantly in stalk strength (Table 8). Other hybrids like the first cycle of selection for stalk strength and the synthetic variety did not change significantly after mid-silking.

The decrease of stalk strength per unit of area with time was more evident in Ames than at Nashua (Table 9). At the highest population level, stalk strength per unit of area did not change significantly from the first to the second harvest.

Table 8. Stalk strength per unit of area as affected by hybrid and harvest time[a]

Harvest time	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	$kg\ cm^{-2}$							
T1	11.0	8.3	6.3	5.9	8.8	9.2	6.0	7.9
T2	11.6	7.4	6.0	5.6	7.0	6.7	4.5	7.0

[a]$LSD_{0.05}$ for harvest time = 0.23; for harvest time at same hybrid = 0.61

Table 9. Stalk strength per unit of area as affected by harvest time, location, and population[a]

Harvest time	Location		Plant population		
	L1	L2	P1	P2	P3
	$kg\ cm^{-2}$				
T1	8.4	7.5	9.2	7.8	6.9
T2	6.7	7.3	7.7	6.7	6.6

[a]$LSD_{0.05}$ for harvest time at same location = 0.33; for harvest time at same plant population = 0.40.

Rind thickness

Plant population, hybrid, and harvest time had a highly significant effect on rind thickness. The interactions of plant population x hybrid and location x harvest time were also highly significant (Table 1).

Rind thickness decreased with increasing population levels (Table 10) but not equally for all hybrids. At the lowest plant population, rind thickness was significantly greater than at the intermediate plant population level for all the hybrids (Figure 2). At this level, however, the values were significantly higher than the highest plant population just for the male sterile with ears covered, the normal counterpart and male sterile. The male-sterile hybrid with ears covered had the greatest rind thickness, followed by the normal cytoplasm and male-sterile, and the latter two were not significantly different from each other. The synthetic variety had the lowest value for rind thickness and the other hybrids were intermediate.

Rind thickness was significantly less for the second harvest than for the first (Table 11), but only at Ames.

Sugar concentration in the sap

The effect of plant population and hybrid on sugar concentration in the sap was highly significant. The effects of plant population x hybrid, location x harvest time, and hybrid x harvest time were also highly significant. The effect of

Table 10. Rind thickness as affected by hybrid and plant population[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	mm							
P1	2.26	1.76	1.62	1.55	1.96	1.94	1.64	1.82
P2	1.76	1.41	1.35	1.36	1.60	1.57	1.43	1.50
P3	1.52	1.32	1.28	1.17	1.35	1.36	1.32	1.33
Mean	1.85	1.50	1.42	1.36	1.64	1.62	1.47	

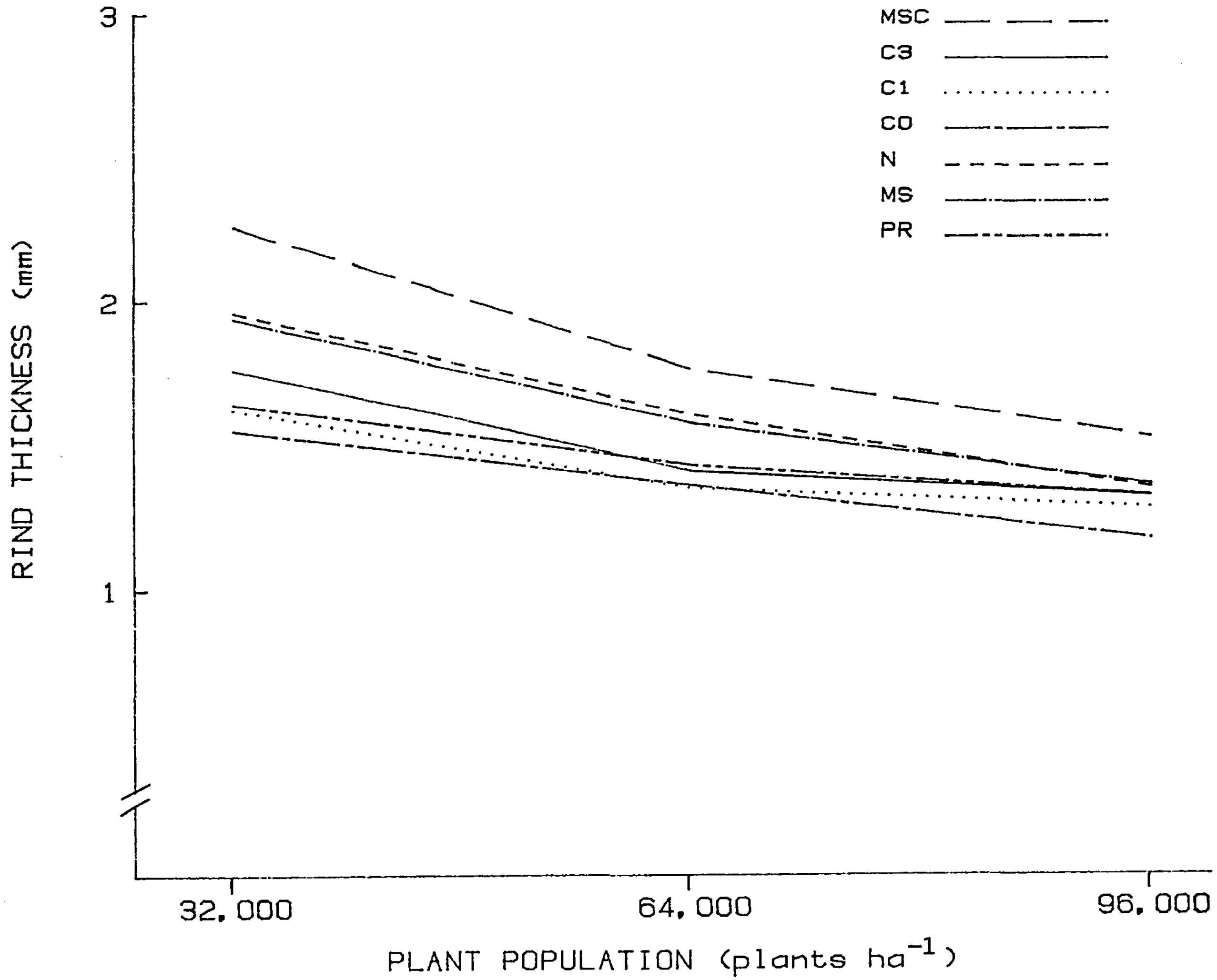
[a] $LSD_{0.05}$ for plant population = 0.07; for hybrid = 0.07; plant population at same or different hybrid = 0.13.

Table 11. Rind thickness as affected by location and harvest time[a]

Harvest time	Location		Mean
	L1	L2	
	mm		
T1	1.70	1.52	1.61
T2	1.48	1.50	1.49

[a] $LSD_{0.05}$ for harvest time = 0.05; for harvest time at same location = 0.06.

Figure 2. Rind thickness as affected by plant population and hybrids


RIND THICKNESS (mm)
3
2
1
MSC
C3
C1
CO
N
MS
PR
32,000
64,000
96,000
PLANT POPULATION (plants ha^{-1})

plant population x harvest time was significant at $p < 0.05$.

Table 12 shows the means as affected by plant population and hybrid. The means for the plant population levels indicate that sugar concentration in the sap was significantly greater at the highest plant density. The male-sterile hybrid with ears covered showed the highest sugar concentration (11.92%), while the prolific had the lowest amount of sugar in the stalk (5.50%). Plant population did not significantly affect the sugar concentration of all hybrids equally (Figure 3). Sugar concentration in the male-sterile hybrid with ears covered tended to decrease with increasing population, whereas for other hybrids, it tended to increase. The first cycle of selection hybrid and the normal cytoplasm showed highest sugar concentration at the highest plant population level which was significantly different from the other two plant population means. Sugar of the synthetic variety was significantly different at all three plant populations.

Sugar concentration at Ames was greater at the second harvest than the first, whereas at Nashua, the opposite was true (Table 13). Harvest time did not significantly affect sugar concentration in the sap at the lowest and medium plant population, but at the highest plant population, sugar concentration was significantly greater at the second harvest.

Sugar concentration did not change significantly with harvest time, but the significant interaction (H x T) is shown

Table 12. Sugar concentration in the sap as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	----------			%			----------	
P1	12.61	6.26	6.60	5.21	5.38	5.34	4.73	6.59
P2	11.86	5.90	6.46	6.53	6.39	6.28	5.47	6.98
P3	11.29	7.29	7.93	7.87	9.25	7.46	6.29	8.20
Mean	11.92	6.48	6.99	6.54	7.01	6.36	5.50	

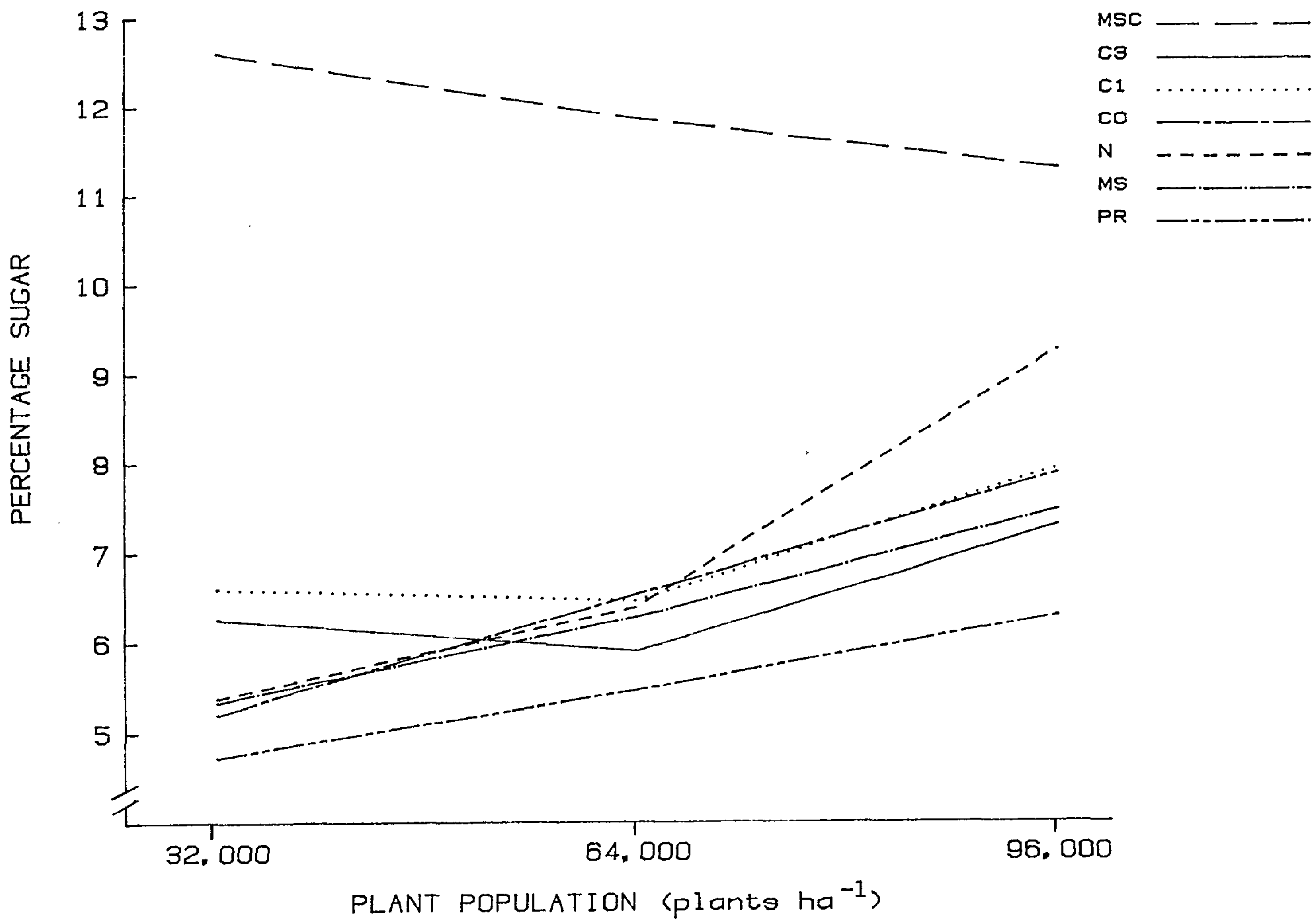
[a]$LSD_{0.05}$ for plant populations = 0.41; for plant population at same or different hybrid = 1.32.

Table 13. Sugar concentration in the sap as affected by harvest time, location, and plant population[a]

Harvest time	Location		Plant population		
	L1	L2	P1	P2	P3
	----------		%		----------
T1	6.35	7.93	6.76	6.89	7.78
T2	7.42	7.32	6.42	7.07	8.62

[a]$LSD_{0.05}$ for harvest time at same location = 0.55; for harvest time at same plant population = 0.67.

Figure 3. Sugar concentration of the sap as affected by plant population and hybrids


PERCENTAGE SUGAR
13
12
11
10
9
8
7
6
5
32,000
64,000
96,000
PLANT POPULATION (plants ha^{-1})
MSC
C3
C1
CO
N
MS
PR

in Table 14. The male-sterile with ears covered showed a large increase of sugar from the first to the second harvest, whereas the other hybrids tended to increase or decrease. The increase in sugar concentration from the first to the second harvest was expected in the male-sterile hybrid with ears covered since there was no grain as a sink to store photosynthates.

Table 14. Sugar concentration in the sap as affected by hybrid and harvest time[a]

Harvest time	Hybrid						
	MSC	C3	C1	C0	N	MS	PR
	%						
T1	10.72	6.10	6.84	6.45	7.33	6.66	5.89
T2	13.13	6.86	7.15	6.62	6.68	6.06	5.10

[a] $LSD_{0.05}$ for harvest time at same hybrid = 1.02.

Stalk moisture for the first harvest

Stalks harvested at Ames had significantly greater moisture (83.13%) than at Nashua (82.13%). Moisture in the stalk was lowest at the highest population density (Table 15). The male-sterile hybrid with ears covered had the least amount of moisture at the first harvest and the prolific had the wettest stalk (Figure 4). The means for the interac-

Table 15. Stalk moisture for the first harvest as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	%							
P1	76.78	83.39	83.89	84.16	83.17	82.51	85.68	82.80
P2	77.98	84.70	84.02	83.25	83.04	82.67	84.32	82.86
P3	79.13	84.25	82.68	81.79	80.52	83.23	84.01	82.23
Mean	77.96	84.11	83.53	83.07	82.24	82.81	84.67	

[a] $LSD_{0.05}$ for plant population = 0.37; for hybrids = 0.85; for plant population at same or different hybrid = 1.51.

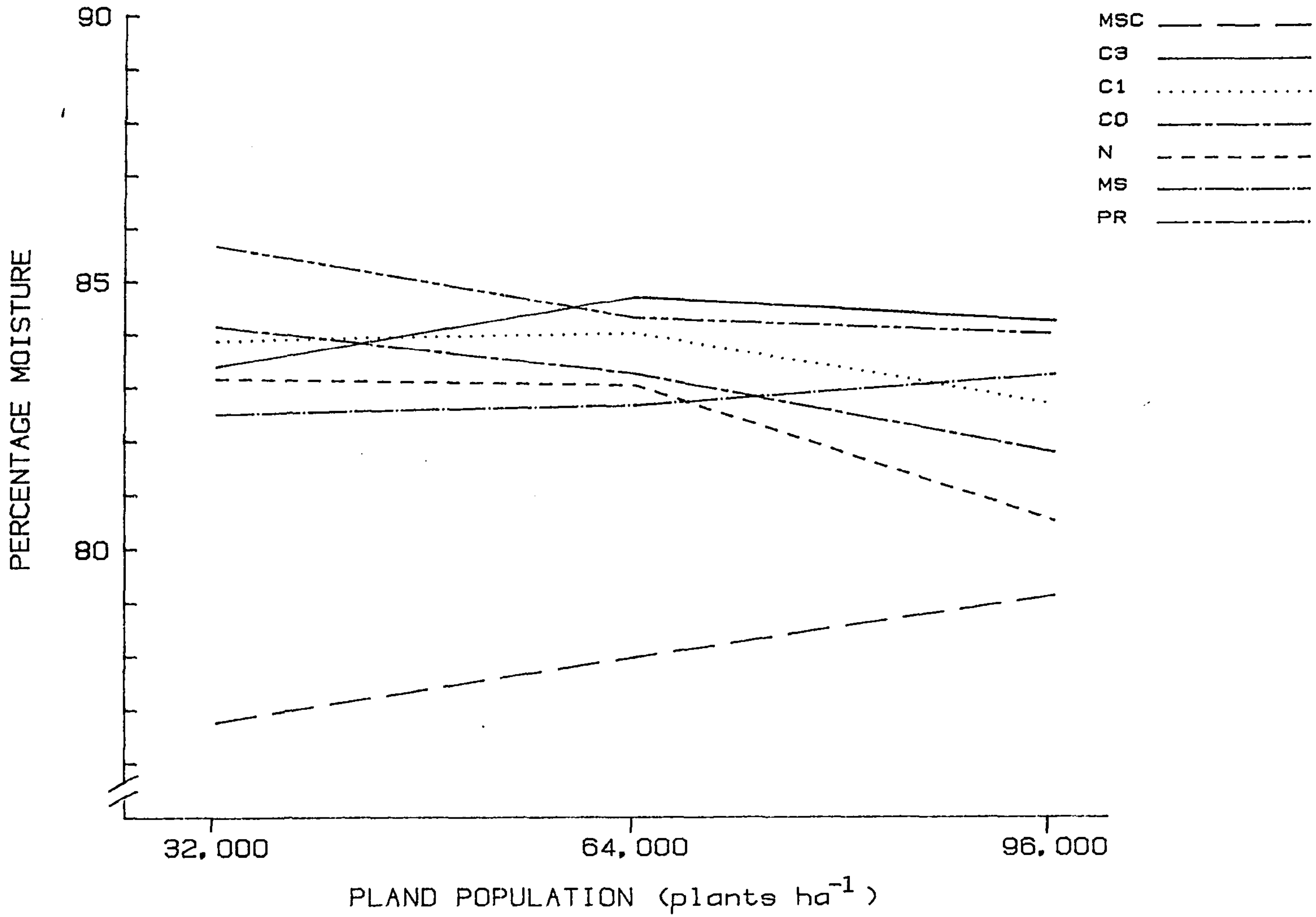
tion show that moisture percentage tended to increase with population for the male-sterile hybrid with ears covered, whereas two tended to decrease and others had mixed effects between the three populations.

Internode

Length Hybrid and harvest time had a significant effect on internode length. The interactions plant population x hybrid and location x harvest time were also highly significant (Table 1).

The prolific hybrid had the greatest internode length (Table 16) and the normal cytoplasm hybrid showed the shortest internodes. The other hybrids were intermediate and there

Figure 4. Stalk moisture for the first harvest as affected by plant population and hybrids



90
85
80
PERCENTAGE MOISTURE
32,000
64,000
96,000
PLAND POPULATION (plants ha-1)
MSC
C3
C1
CO
N
MS
PR

Table 16. Length of the internode as affected by plant population and hybrid[a]

Plant pop.	Hybrid						
	MSC	C3	C1	C0	N	MS	PR
	cm						
P1	13.9	13.6	13.2	13.2	13.3	13.8	14.5
P2	13.3	13.1	13.8	13.6	12.5	13.2	16.1
P3	13.5	13.7	14.4	12.9	12.0	13.0	15.7
Mean	13.5	13.4	13.8	13.2	12.6	13.3	15.5

[a]$LSD_{0.05}$ for hybrid = 0.56; for plant population at same or different hybrid = 1.18.

was no significant difference between them (Figure 5). Population level only significantly affected the length of the internode of the prolific, which was significantly lower at the lowest population level. Internodes were longer at the second harvest (Table 17). The length differed between harvests only at Ames. At Nashua, there was no significant difference in internode length between the two harvests.

Diameter Plant population and hybrid had a highly significant effect on internode diameter. There were no significant interactions. Increasing population caused a decrease in stalk diameter (Table 18). The hybrid with the largest diameter was the prolific. The smallest diameter was found on the third cycle of selection hybrid and the

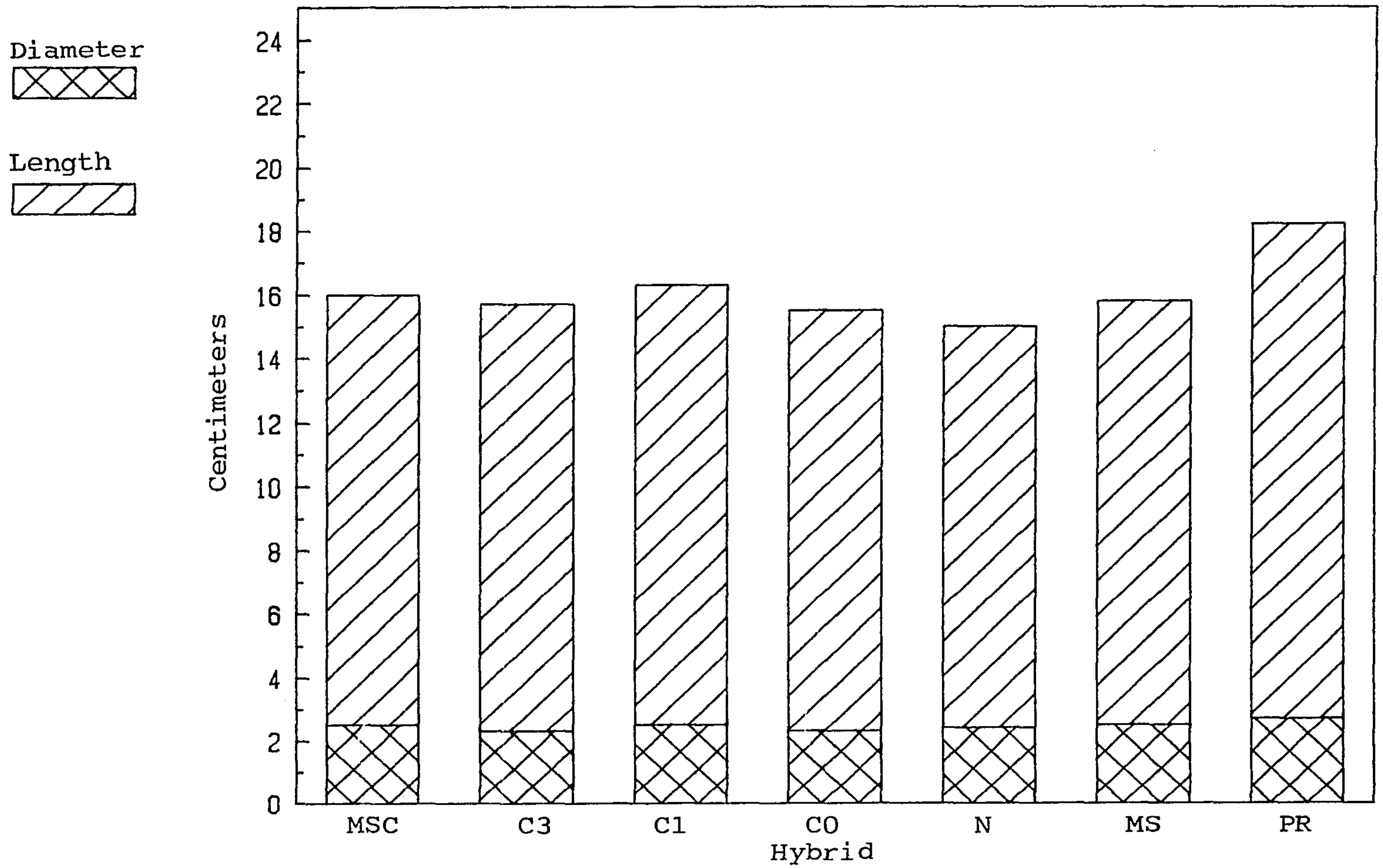


Figure 5. Diameter and length of the internode as affected by hybrids

Table 17. Length of the internode as affected by harvest time and location[a]

Harvest time	Location L1	L2	Mean
	----------cm----------		
T1	12.5	13.9	13.2
T2	14.1	14.0	14.1

[a] $LSD_{0.05}$ for harvest time = 0.22; for harvest time at same location = 0.32.

Table 18. Diameter of the internode as affected by plant population and hybrid[a]

Plant population			Hybrid						
P1	P2	P3	MSC	C3	C1	CO	N	MS	PR
				----cm----					
2.8	2.4	2.2	2.5	2.3	2.5	2.3	2.4	2.5	2.7

[a] $LSD_{0.05}$ for plant population = 0.05; for hybrid = 0.08.

synthetic variety. The other hybrids were intermediate and there was no significant difference between them.

Volume   Plant populations and hybrid had highly significant effects on the volume of the internode. Harvest time and the interaction of location x harvest time were also highly significant.

Volume of the internode (Table 19) decreased significantly with increasing population levels. The prolific hybrid had the highest volume and the synthetic variety, as well as the third cycle of selection hybrid, showed the least volume for the internode (Figure 6). The other hybrids were intermediate in volume.

Volume of the internode was greatest at the second harvest (Table 20) but that trend was highly significant only at Ames. This explains the significant location x harvest time interaction.

Forage Quality

Acid detergent fiber

Whole internode   Location had a significant effect ($p<0.05$) on ADF of the internode. The main effects of population, hybrid, and harvest time were highly significant, and the interactions plant population x hybrid, location x harvest time, population x harvest time, and hybrid x harvest were also highly significant (Table 1).

Table 19. Volume of the internode as affected by plant population and hybrid[a]

Plant population			Hybrid						
P1	P2	P3	MSC	C3	C1	CO	N	MS	PR
				cm^3					
84.7	62.4	52.0	66.6	59.1	66.3	58.2	61.6	64.6	88.5

[a]$LSD_{0.05}$ for plant population = 4.2; for hybrid = 5.2.

Table 20. Volume of the internode as affected by location and harvest time[a]

Harvest time	Location L1	L2	Mean
	cm^3		
T1	60.7	68.8	64.8
T2	66.3	69.7	68.0

[a]$LSD_{0.05}$ for harvest time = 1.6; for harvest time at same location = 2.3.

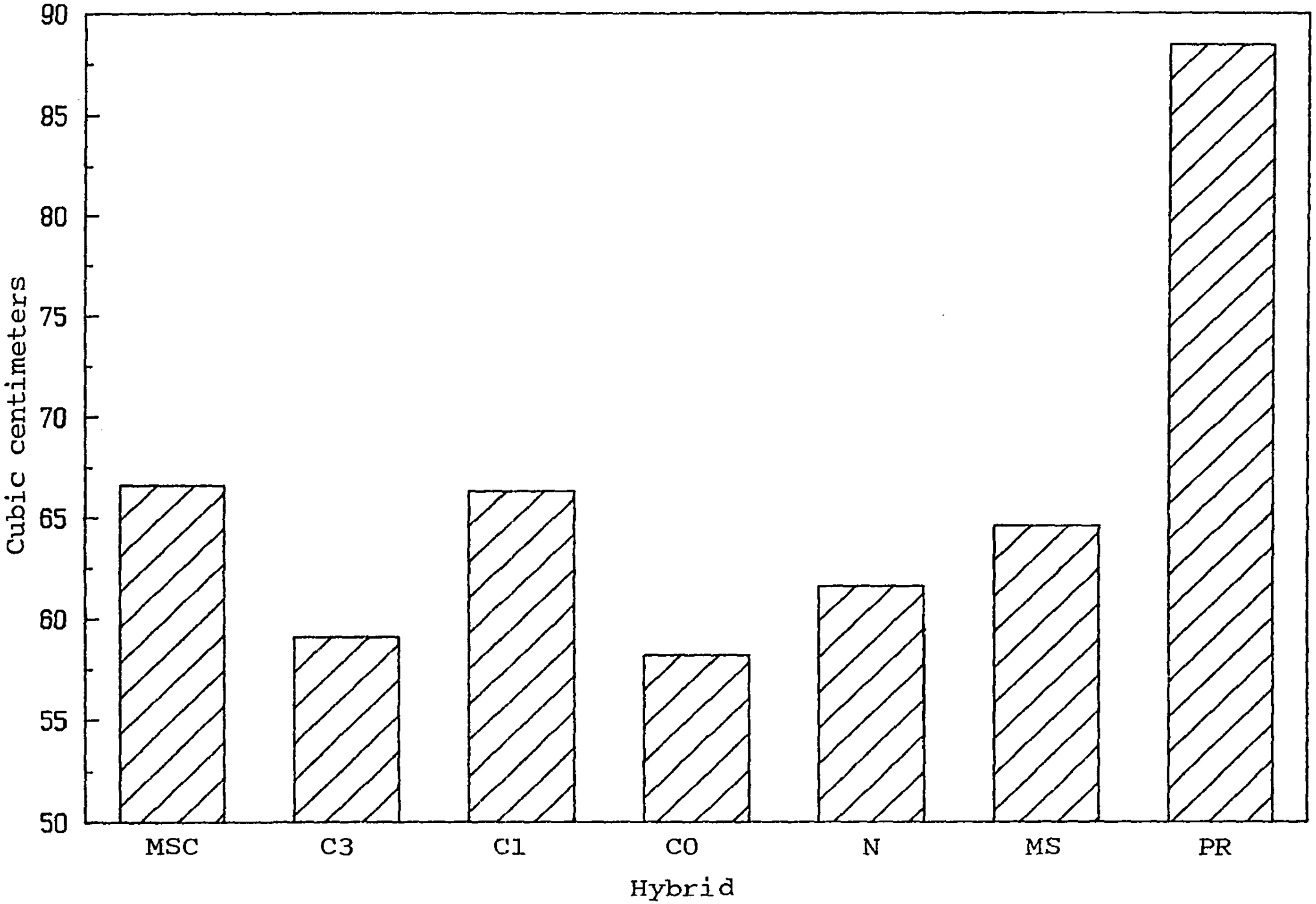


Figure 6. Volume of the internode as affected by hybrids

Acid detergent fiber in the internode was significantly higher at Ames (48.85%) than at Nashua (39.11%). The overall means for plant population (Table 21) indicate that percentage ADF in the internode was least at the highest population level, and there was no difference between the first and second population levels. The means for the interaction indicate that this did not happen equally with all the hybrids. For the male-sterile hybrid with ears covered and the third cycle of selection, there were no significant differences in percentage ADF due to plant population, but with other hybrids, the differences were greater between P2 and P3 than between P1 and P2 except for the prolific where the effect of population was noticeable even before reaching the highest population level.

On the average, the prolific hybrid had the greatest ADF, followed by the male-sterile hybrid which also was significantly different from the others (Figure 7). The normal cytoplasm and the synthetic variety were intermediate, and the first and third cycles of selection and male-sterile with ears covered showed the least amount of ADF in the whole internode.

Acid detergent fiber of the internode (Table 22) was greatest at the second harvest and this was true for both locations, and also within each population level.

All the hybrids had greatest ADF in the internode at the second harvest (Table 23) except the male-sterile hybrid with ears covered which showed no significant differences between

Table 21. Whole internode ADF as affected by plant population and hybrid[a]

Plant pop.	Hybrid MSC	C3	C1	C0	N	MS	PR	Mean
	----------%----------							
P1	34.01	39.08	40.63	43.94	45.59	45.40	50.08	42.68
P2	33.80	40.22	39.24	42.77	43.24	43.02	45.79	41.15
P3	32.44	36.71	35.95	36.83	34.91	40.61	45.81	37.61
Mean	33.41	38.67	38.61	41.18	41.25	43.01	47.23	

[a]$LSD_{0.05}$ for plant population = 1.72; for hybrid = 1.64; for plant population at same or different hybrid = 3.27.

Table 22. Whole internode ADF as affected by location and plant population[a]

Harvest time	Location L1	L2	Plant population P1	P2	P3	Mean
	----------%----------					
T1	40.91	36.36	40.01	39.02	36.86	38.63
T2	42.78	41.87	45.34	43.28	38.35	42.32

[a]$LSD_{0.05}$ for harvest time = 0.73; for harvest time at same location = 1.03; for harvest time at same plant population = 1.26.

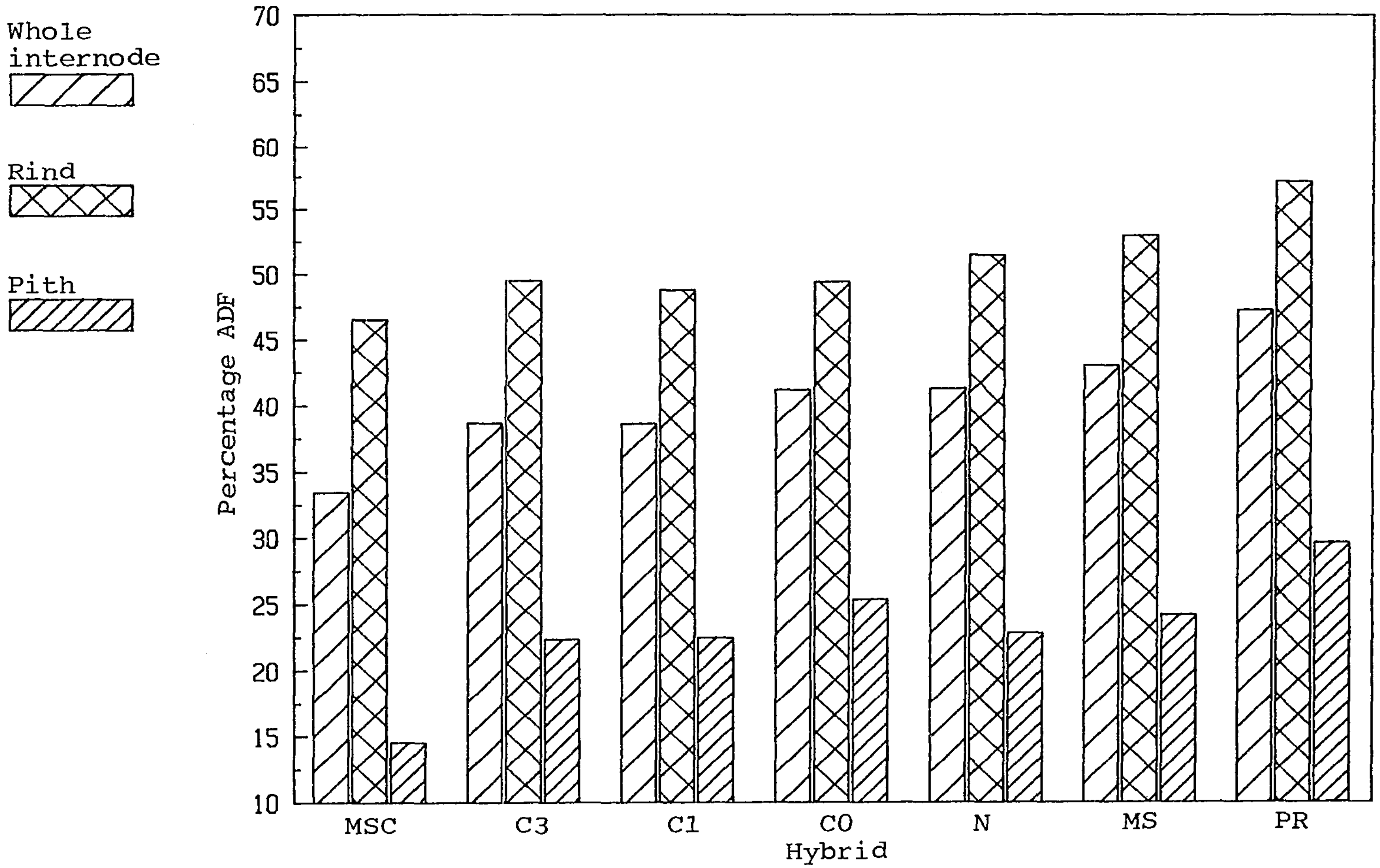


Figure 7. Whole internode, rind, and pith ADF as affected by hybrids

harvests.

To eliminate the dilution effect of the total nonstructural carbohydrates, ADF of the whole internode was evaluated on a dry matter basis from which sugars were subtracted. Thus, hybrids had a highly significant effect on percentage ADF of the whole internode (Table 24). Main effects of plant population and the hybrid x plant population interaction were not significant, however. The prolific hybrid had the greatest value of ADF adjusted (Figure 8).

Rind Plant population, hybrid and harvest time had a highly significant effect on percentage ADF of the rind. The interactions of plant population x hybrid, plant population x harvest time, and hybrid x harvest time were highly significant but the interaction location x harvest time was significant only at $p < 0.05$.

Acid detergent fiber of the rind (Table 25) was significantly lower at the highest population. There were no significant differences between the first and second population levels except for the male-sterile hybrid where percentage ADF of the rind decreased with increasing plant population. The male-sterile hybrid with ears covered, the third cycle of selection, and the prolific did not show any significant difference in percentage ADF of the rind caused by increasing plant population. The overall hybrid means indicate that the prolific had the highest amount of percentage ADF of the rind,

Table 23. Whole internode ADF as affected by harvest time and hybrid[a]

Harvest time	Hybrid						
	MSC	C3	C1	CO	N	MS	PR
	%						
T1	34.30	37.21	37.31	39.12	38.75	39.54	44.20
T2	32.52	40.13	39.91	43.24	43.74	46.48	50.26

[a] $LSD_{0.05}$ for harvest time at same hybrid = 1.93.

Table 24. Whole internode ADF on dry matter basis corrected for sugar concentration, for the first harvest[a]

Hybrid						
MSC	C3	C1	CO	N	MS	PR
%						
55.40	54.99	57.11	57.29	58.73	59.37	66.43

[a] $LSD_{0.05}$ = 4.95.

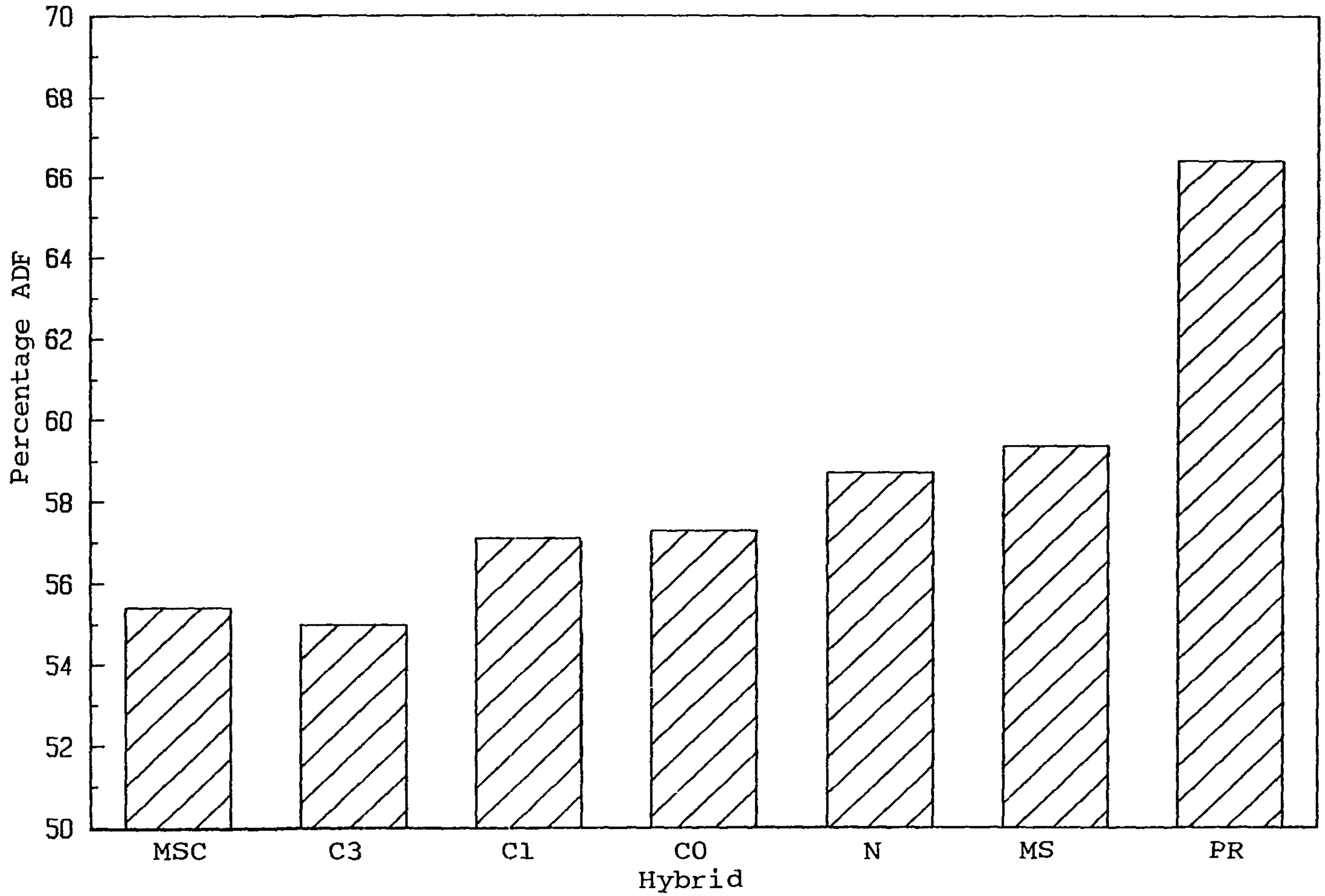


Figure 8. Whole internode ADF adjusted as affected by hybrids

Table 25. Rind ADF as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	C0	N	MS	PR	
	%							
P1	47.76	50.24	50.83	51.35	54.81	55.71	58.33	52.72
P2	46.26	50.00	49.46	50.44	53.46	52.87	56.71	51.31
P3	45.65	48.17	46.01	46.33	46.08	50.20	56.32	48.39
Mean	46.56	49.47	48.76	49.37	51.45	52.92	57.12	

[a]$LSD_{0.05}$ for plant population = 1.46; for hybrid = 1.36; for plant population at same or different hybrid = 2.74.

followed by the male-sterile and the normal counterpart (Figure 7). Male-sterile with ears covered showed the least percentage ADF of the rind, and the other three hybrids (C3, C1, and C0) were intermediate.

Time of harvest also significantly affected the percentage of ADF in the rind (Table 26) which was greatest in the second harvest at both locations and plant population levels. The interaction with time for each of these two variables was still significant. Table 27 shows that ADF of the rind did not change with time for the male-sterile hybrid with ears covered but changed significantly in all other hybrids, being greater in the second harvest.

Table 26. Rind ADF as affected by location and plant population[a]

Harvest time	Location		Plant population			Mean
	L1	L2	P1	P2	P3	
	--------	--------	%	--------	--------	
T1	49.80	48.51	50.72	49.08	47.67	49.16
T2	52.47	52.45	54.72	53.54	49.12	52.46

[a] $LSD_{0.05}$ for harvest time = 0.64; for harvest time at same location = 0.90; for harvest time at same plant population = 1.10.

Table 27. Rind ADF as affected by harvest time and hybrid[a]

Harvest time	Hybrid						
	MSC	C3	C1	CO	N	MS	PR
	--------	--------	--------	%	--------	--------	--------
T1	46.42	48.16	46.94	47.55	49.95	50.63	54.47
T2	46.70	50.78	50.59	51.20	52.96	55.22	59.78

[a] $LSD_{0.05}$ for harvest time at same hybrid = 1.69.

Pith The effects of plant population, hybrid, and harvest time on percentage ADF of the pith were highly significant. The interactions plant population x hybrid, location x harvest time, population x harvest time, and hybrid x harvest time were also highly significant.

The overall means for percentage ADF as affected by plant population (Table 28) indicate that increasing plant population caused ADF of the pith to decrease significantly at all levels. Plant population had large effects on ADF for synthetic variety, normal and prolific hybrids but little effect on the others. The overall means for the hybrids indicate that highest percentage of ADF of the pith was found on the prolific followed by the synthetic variety. These genotypes had the weakest stalks (Table 4). The lowest value for ADF of the pith was found in the male-sterile hybrid with ears covered, which had the strongest stalks (Figure 7). The other hybrids were intermediate.

Acid detergent fiber of the pith increased significantly with time (Table 29), and this occurred at both locations and at each population level. Even with similar trends, the interactions with harvest time were significant. The same thing happened with all hybrids with respect to time (Table 30), except for the male-sterile hybrid with ears covered where ADF of the pith increased only slightly from the first to the second harvest.

Table 28. Pith ADF as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	----------------------			%			----------------------	
P1	15.28	21.79	24.92	28.82	26.93	27.04	34.26	25.58
P2	14.16	22.81	22.66	26.38	24.12	24.11	28.00	23.18
P3	14.15	22.39	19.76	20.84	17.39	21.35	26.59	20.35
Mean	14.53	22.33	22.45	25.35	22.81	24.17	29.61	

[a]$LSD_{0.05}$ for plant population = 2.18; for hybrid = 1.81; for plant population at same or different hybrid = 3.74.

Table 29. Pith ADF as affected by harvest time, location, and plant population[a]

Harvest time	Location		Plant population			Mean
	L1	L2	P1	P2	P3	
	------------------		%		------------------	
T1	22.15	18.76	22.08	20.53	18.76	20.45
T2	25.20	26.03	29.08	25.82	21.95	25.62

[a]$LSD_{0.05}$ for harvest time = 0.84; for harvest time at same location = 1.19; for harvest time at same plant population = 1.46.

Table 30. Pith ADF as affected by harvest time and hybrid[a]

Harvest time	Hybrid MSC	C3	C1	C0	N	MS	PR
	---	---	---	%	---	---	---
T1	14.16	20.55	20.68	23.19	19.20	20.11	25.28
T2	14.90	24.11	24.21	27.50	26.41	28.23	13.94

[a]$LSD_{0.05}$ for harvest time at same hybrid = 2.23.

Acid detergent lignin

Whole internode Location had a significant effect ($p<0.05$), and plant population, hybrid, and harvest time had highly significant effects on percentage ADL of the internode. The first-order interactions plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time were also highly significant (Table 1).

Acid detergent lignin of the internode at Ames (6.97%) was greater than at Nashua (5.48%). In general, plant population affected ADL in the internode but just the highest plant population level was significantly decreased compared with the second level (Table 31). That trend was not verified in all hybrids. For the male-sterile with ears covered, third cycle of selection, and male-sterile, population did not have any significant effect on the ADL of the stalk. For the

Table 31. Whole internode ADL as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	C0	N	MS	PR	
	%							
P1	5.38	6.35	7.21	5.50	6.41	5.08	4.83	6.18
P2	5.17	6.68	5.01	6.02	7.18	4.70	5.90	6.00
P3	5.87	6.57	5.53	6.39	4.61	5.03	7.82	5.42
Mean	5.00	5.26	5.36	5.80	5.97	6.29	7.40	

[a]$LSD_{0.05}$ for plant population = 0.40; for hybrid = 0.42; for plant population at same or different hybrid = 0.82.

prolific hybrid, increasing population caused a significant increase in percentage ADL at all levels. The overall means for the hybrids indicate that the prolific had the greatest percentage ADL value, followed by the male-sterile with 6.29%. The least amounts of ADL were found for the third and first cycle of selection for stalk strength, and for the male-sterile with ears covered (Figure 9). Acid detergent lignin increased significantly with time (Table 32), only at Nashua. Also, for each plant population level and hybrid (Table 33), percentage ADL in the internode increased significantly with time except for the highest population level for the male-sterile hybrid with ears covered, and the first cycle of

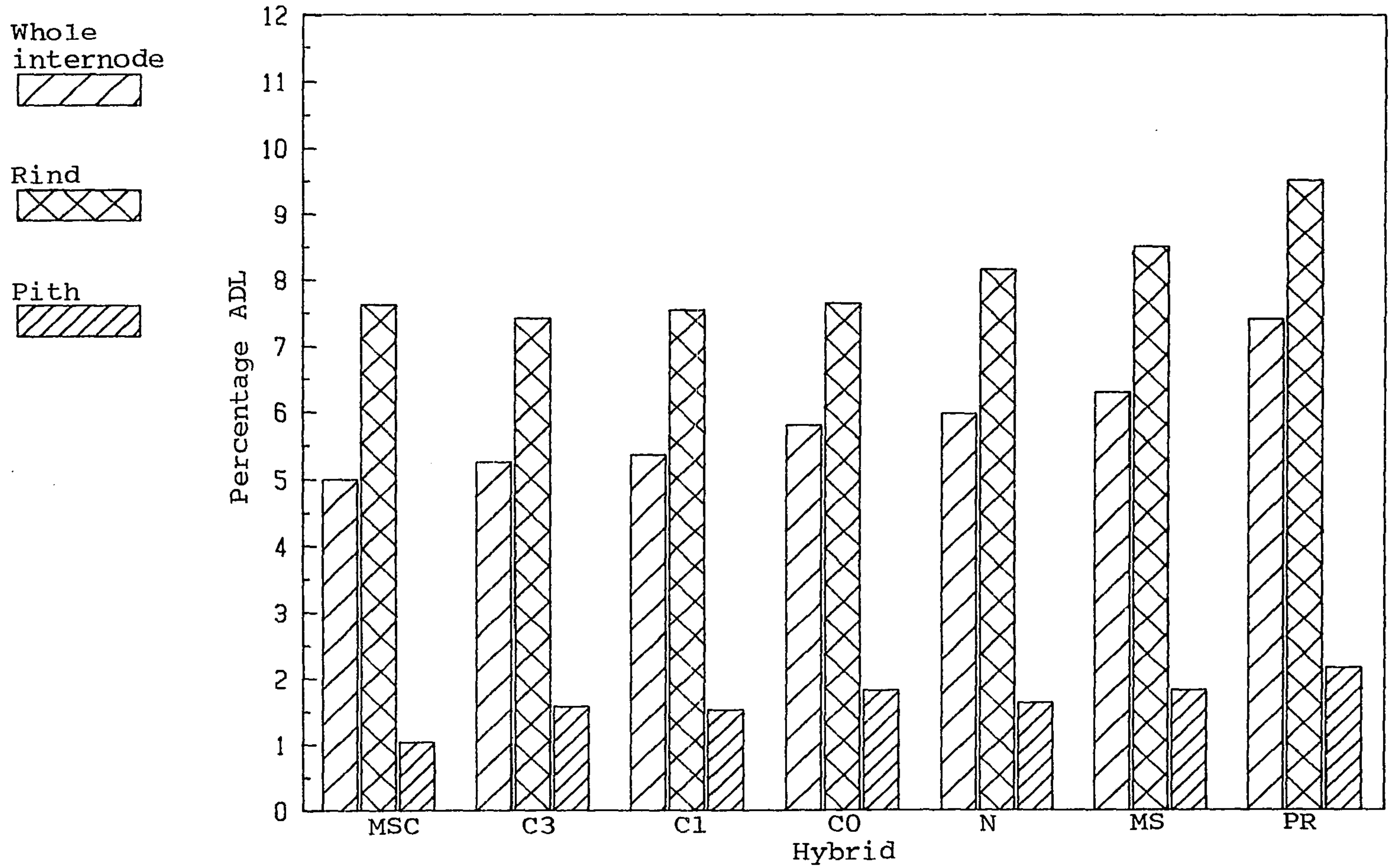


Figure 9. Whole internode, rind, and pith ADL as affected by hybrids

Table 32. Whole internode ADL as affected by location and harvest time[a]

Harvest time	Location L1	L2	Mean
	-----------%----------		
T1	6.17	4.87	5.52
T2	6.36	6.08	6.22

[a]$LSD_{0.05}$ for harvest time = 0.18; for harvest time at same location = 0.26.

Table 33. Whole internode ADL as affected by harvest time, plant population and hybrid[a]

Plant population P1	P2	P3	Hybrid MSC	C3	C1	CO	N	MS	PR
				-----%-----					
T1									
5.68	5.59	5.29	5.08	4.97	5.15	5.43	5.47	5.74	6.80
T2									
6.67	6.42	5.56	4.92	5.55	5.57	6.16	6.46	6.85	8.01

[a]$LSD_{0.05}$ for harvest time at same plant population = 0.31; for harvest time at same hybrid = 0.48.

selection for stalk strength. For those, time had no significant effect on internode ADL percentage

Percentage ADL of the whole internode was also calculated on a dry matter basis with sugars subtracted. Then, location had a significant effect ($p<0.05$) and hybrid had a highly significant effect. Also, on this basis, whole internode ADL was higher at Ames (8.99%) than at Nashua (7.66%).

The prolific hybrid showed the highest percentage of ADL of the whole internode adjusted, and the third cycle of selection for stalk strength showed the lowest value (Table 34). There were no significant differences between the male-sterile with ears covered, male-sterile, and the normal cytoplasm (Figure 10).

<u>Rind</u> The effect of plant population on rind percentage ADL was significant at $p < 0.05$. Hybrid and harvest time, as well as the interaction hybrid x harvest time, had highly significant effects. The effects of the interactions plant population x hybrid and plant population x harvest time were significant at p 2 0.05. The effect of the other interactions was not significant.

Increasing population decreased ADL of the rind, particularly from the middle to the highest population (Table 35). The prolific hybrid showed the opposite trend with population. Percentage ADL of the 1st, 2nd, 3rd, and 4th hybrids in the table was not affected much by population. The prolific

Table 34. Whole internode ADL on dry matter basis corrected for sugar concentration, for the first harvest[a]

Hybrid						
MSC	C3	C1	C0	N	MS	PR
%						
8.18	7.32	7.85	7.94	8.26	8.53	10.20

[a] $LSD_{0.05}$ = 0.8.

Table 35. Rind ADL as affected by plant population and hybrid[a]

Plant pop.	Hybrid MSC	C3	C1	C0	N	MS	PR	Mean
	%							
P1	7.88	7.40	8.09	7.90	8.96	9.20	9.04	8.35
P2	7.64	7.59	7.77	7.83	8.58	7.97	9.29	8.10
P3	7.38	7.26	6.77	7.19	6.92	8.32	10.19	7.72
Mean	7.63	7.42	7.54	7.64	8.15	8.50	9.51	

[a] $LSD_{0.05}$ for plant population = 0.42; for hybrid = 0.60; for plant population at same or different hybrid = 1.11.

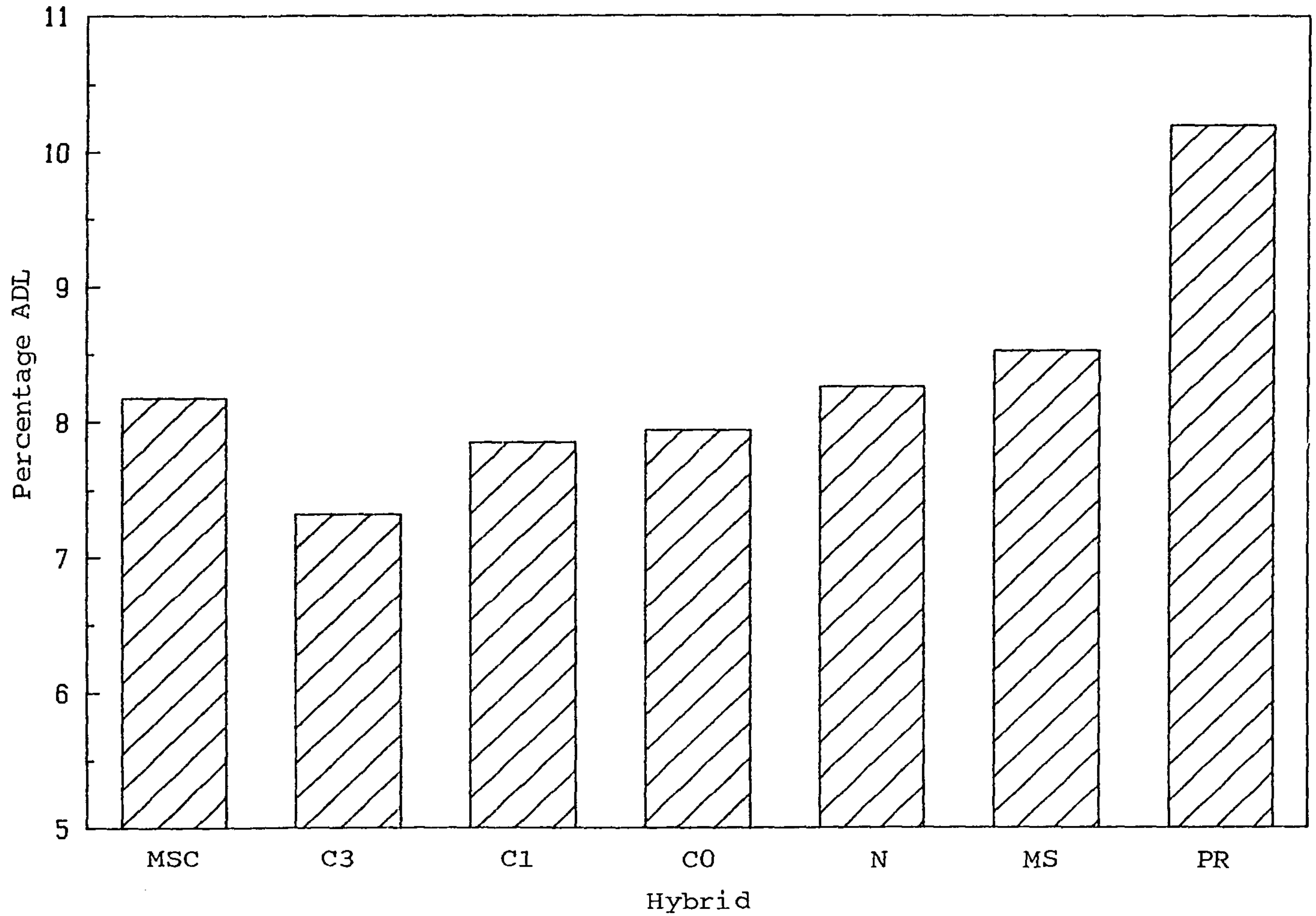


Figure 10. Whole internode ADL adjusted as affected by hybrids

hybrid showed the greatest percentage of ADL of the rind (Figure 9). There was no significant difference among the other hybrids.

Acid detergent lignin of the rind was significantly hibher at the second harvest, but for some hybrids such as male-sterile with ears covered, third and first cycle of selection, and the normal cytoplasm hybrid, there was no significant difference with time (Table 36). The interaction of population and harvest time also is shown in Table 36. The intermediate population level had significantly higher percentage ADL at the second harvest than at the first, whereas this was not significant for the low and high populations.

Pith Hybrid and harvest time had a highly significant effect on percentage ADL of the pith. The interaction plant population x hybrid was significant at $p < 0.05$ and the interactions location x harvest time and hybrid x harvest time were highly significant.

The prolific hybrid had significantly higher percentage of ADL in the pith than the others (Table 37). The male-sterile hybrid with ears covered analyzed lowest in percentage ADL in the pith (Figure 9), and was least affected by population. In general, there was a trend for the amount of ADL in the pith to decrease with population for most of the hybrids.

Acid detergent lignin of the pith was significantly

Table 36. Rind ADL as affected by plant population and hybrid[a]

Harvest time	Plant population			Hybrid							Mean
	P1	P2	P3	MSC	C3	C1	C0	N	MS	PR	
	%										
T1	8.14	7.56	7.58	7.66	7.40	7.36	7.21	8.09	8.00	8.61	7.76
T2	8.57	8.63	7.86	7.61	7.44	7.73	8.07	8.22	9.00	10.41	8.35

[a]$LSD_{0.05}$ for harvest time = 0.27; for harvest time at same plant population = 0.44; for harvest time at same hybrid = 0.68.

Table 37. Pith ADL as affected by plant population and hybrid[a]

Plant pop.	Hybrid						
	MSC	C3	C1	C0	N	MS	PR
				%			
P1	1.01	1.48	1.70	2.02	1.90	1.98	2.47
P2	1.05	1.47	1.55	1.98	1.79	1.79	1.93
P3	1.05	1.80	1.32	1.46	1.19	1.70	2.07
Mean	1.04	1.58	1.52	1.82	1.63	1.82	2.16

[a]$LSD_{0.05}$ for hybrid = 0.24; for plant population at same or different hybrid = 0.47.

Table 38. Pith ADL as affected by location, harvest time, and hybrid[a]

Location		Hybrid							
L1	L2	MSC	C3	C1	C0	N	MS	PR	Mean
					%				
T1									
1.53	1.25	1.07	1.35	1.40	1.53	1.25	1.46	1.66	1.39
T2									
1.83	2.01	1.01	1.82	1.64	2.11	2.00	2.19	2.65	1.92

[a]$LSD_{0.05}$ for harvest time = 0.12; for harvest time at same location = 0.16; for harvest time at same hybrid = 0.31.

greater at the second harvest (Table 38) and this occurred at both locations and for most of the hybrids except for the male-sterile hybrid with ears covered and the first cycle of selection for stalk strength.

<u>*In vitro* dry matter disappearance</u>

<u>Whole internode</u> Location had a significant effect ($p<0.05$), and plant population, hybrid, harvest time, plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time had highly significant effects ($p<0.01$) on IVDMD of the whole internode (Table 1). At Nashua, IVDMD of the internode (54.55%) was significantly greater than at Ames (51.64%). Increasing population resulted in an increase in IVDMD of the internode (Table 39), but for some hybrids, like male-sterile hybrid with ears covered, third cycle of selection, and male-sterile, the effect of population was smaller than for the other hybrids. The overall means for the hybrids indicate that the male-sterile hybrid with ears covered had the greatest IVDMD value and was followed by the first and third cycle of selection for stalk strength (Figure 11). The least IVDMD was found for the prolific hybrid.

Time also affected IVDMD of the internode. Table 40 shows higher values for the first harvest. The same was observed at both locations and at each population level except for the highest plant density where the difference between

Table 39. Whole internode IVDMD as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	----------------------%----------------------							
P1	61.23	55.02	52.27	46.34	47.96	48.27	39.41	50.07
P2	61.65	53.22	56.02	49.86	50.17	50.59	46.50	52.57
P3	63.03	56.98	58.95	57.65	60.42	53.25	46.22	56.64
Mean	61.97	55.07	55.75	51.28	52.85	50.70	44.04	

[a]$LSD_{0.05}$ for plant population = 2.39; for hybrid = 1.97; plant population at same or different hybrid = 4.09.

Table 40. Whole internode IVDMD as affected by harvest time, location, and plant population[a]

Harvest time	Location		Plant population			Mean
	L1	L2	P1	P2	P3	
	--------------------%--------------------					
T1	52.69	57.65	53.31	54.88	57.33	55.17
T2	50.59	51.44	46.83	50.26	55.96	51.01

[a]$LSD_{0.05}$ for harvest time = 0.89; for harvest time at same location = 1.25; for harvest time at each plant population = 1.53.

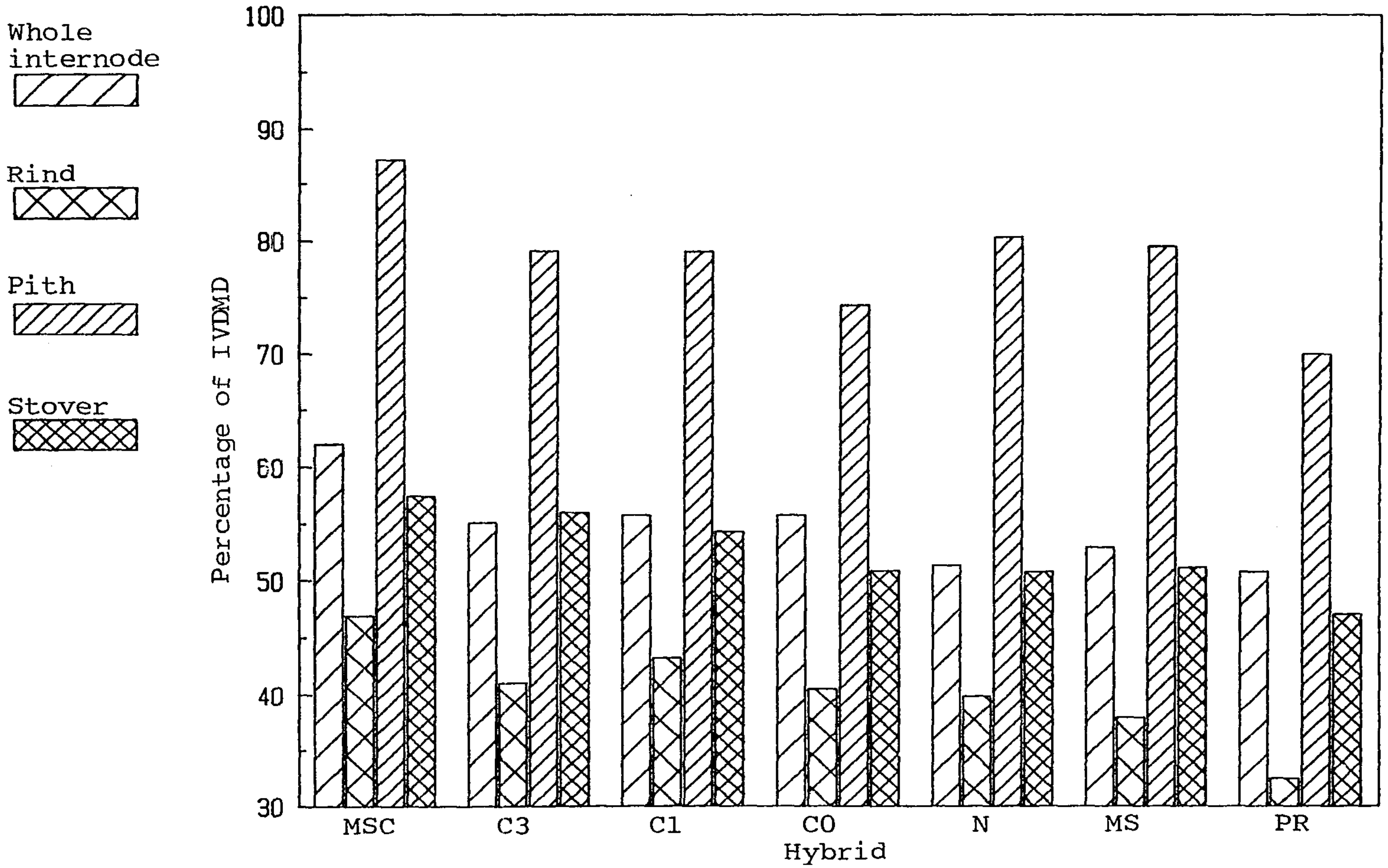


Figure 11. Whole internode, rind, pith, and stover IVDMD as affected by hybrid

harvests was not significant.

The IVDMD decreased in all the hybrids from the first to the second harvest except for the male-sterile hybrid with ears covered (Table 41), which is not surprising since, with this hybrid, the sugars were not mobilized to the ear.

Rind Plant population, hybrid, and harvest time had a highly significant effect on IVDMD of the rind as did the first-order interactions of plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time.

The rind IVDMD increased significantly with increasing plant population, but this did not happen equally with all hybrids (Table 42). The IVDMD of the three hybrids in the center of the table was affected more by population than was IVDMD of the other four hybrids. The overall means for the hybrids indicate that male-sterile hybrid with ears covered had the greatest value for IVDMD of the rind (46.89%) as shown in Figure 11. The first cycle of selection hybrid had also a high value compared with the others. The prolific hybrid showed the lowest value.

The rind IVDMD decreased significantly from the first to the second harvest for each plant population level, at each location (Table 43), and for each hybrid (Table 44) except for the male-sterile with ears covered which showed no significant difference between harvests even though there is a trend for

Table 41. Whole internode IVDMD as affected by harvest time and hybrid[a]

Harvest time	Hybrid						
	MSC	C3	C1	CO	N	MS	PR
	---%						
T1	61.11	56.81	57.08	53.64	55.31	54.22	48.03
T2	62.83	53.34	54.41	48.92	50.38	47.18	40.05

[a]$LSD_{0.05}$ for harvest time at same hybrid = 2.34.

Table 42. Rind IVDMD as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	---%							
P1	45.56	40.40	39.13	35.74	35.47	35.63	30.11	37.43
P2	46.72	40.17	43.66	39.90	36.47	38.03	33.18	39.73
P3	48.40	42.45	47.08	45.85	47.65	40.01	34.08	43.64
Mean	46.89	41.00	43.29	40.50	39.86	37.89	32.46	

[a]$LSD_{0.05}$ for plant population = 2.06; for hybrid = 1.84; for plant population at same or different hybrid = 3.74.

Table 43. Rind IVDMD as affected by harvest time, location, and plant population[a]

Harvest time	Location		Plant population			Mean
	L1	L2	P1	P2	P3	
	%					
T1	41.72	43.18	40.32	42.29	44.75	42.45
T2	39.06	37.11	34.54	37.18	42.54	38.09

[a]$LSD_{0.05}$ for time = 0.74; for harvest time at same location = 1.05; for harvest time at same population = 1.28.

Table 44. Rind IVDMD as affected by harvest time and hybrid[a]

Harvest time	Hybrid						
	MSC	C3	C1	CO	N	MS	PR
	%						
T1	46.63	42.79	45.45	42.55	42.40	41.07	36.27
T2	47.16	39.22	41.13	38.44	37.32	34.71	28.64

[a]$LSD_{0.05}$ for harvest time at same hybrid = 1.96.

IVDMD to increase with time.

Pith The effects of plant population, hybrid, harvest time, plant population x hybrid, location x harvest time, plant population x harvest time, and hybrid x harvest time were highly significant.

Increasing plant population caused an increase in IVDMD of the pigh (Table 45), but this effect was greater for some hybrids like the prolific, the synthetic variety, and the normal cytoplasm. The IVDMD for the male-sterile hybrid with ears covered was little affected by population. The overall means for the hybrids show the male-sterile with ears covered with the greatest percentage of IVDMD of the pith, followed by the synthetic variety which was also significantly different from the others (Figure 11). The prolific showed the least value. The digestibility of the pith decreased significantly with time (Table 46) and this was true for each location, at each plant population level, and for each hybrid (Table 47), except for the male-sterile with ears covered which showed no significant difference between harvests.

Stover The effects of plant population, hybrid, and the first-order interaction plant population x hybrid were highly significant. The effects of location x hybrid and location x plant population x hybrid were also significant but just at $p < 0.05$. At the highest plant population level, the stover was significantly more digestible than at low and

Table 45. Pith IVDMD as affected by plant population and hybrid[a]

Plant pop.	Hybrid							Mean
	MSC	C3	C1	CO	N	MS	PR	
	---%							
P1	86.61	80.54	76.22	70.02	77.15	77.34	62.25	75.73
P2	87.41	78.24	79.41	72.87	79.27	79.54	72.26	78.43
P3	87.39	78.39	81.45	79.97	84.20	81.41	75.13	81.13
Mean	87.14	79.06	79.03	74.28	80.21	79.43	69.88	

[a]$LSD_{0.05}$ for plant population = 2.65; for hybrid = 2.31; plant population at same or different hybrid = 4.71.

Table 46. Pith IVDMD as affected by harvest time, location, and plant population[a]

Harvest time	Location		Plant population			Mean
	L1	L2	P1	P2	P3	
	---%					
T1	80.04	82.24	79.48	81.21	82.73	81.14
T2	76.38	75.07	71.98	75.65	79.53	75.72

[a]$LSD_{0.05}$ for harvest time = 0.82; for harvest time at same location = 1.16; for harvest time at same plant population = 1.42.

Table 47. Pith IVDMD as affected by harvest time and hybrid[a]

Harvest time	Hybrid MSC	C3	C1	CO	N	MS	PR
	------------	------------	------------	%	------------	------------	------------
T1	87.08	81.49	81.19	76.77	83.60	83.09	74.76
T2	87.19	76.62	76.86	71.80	76.82	75.77	65.00

[a]$LSD_{0.05}$ for harvest time at same hybrid = 2.17.

Table 48. Stover IVDMD as affected by plant population and hybrid[a]

Plant pop.	Hybrid MSC	C3	C1	CO	N	MS	PR	Mean
	------------	------------	------------	%	------------	------------	------------	
P1	60.62	53.65	53.32	50.72	48.36	50.72	47.03	51.40
P2	56.18	53.68	54.83	49.00	50.11	50.28	44.45	50.84
P3	55.63	60.57	54.72	52.68	53.70	52.18	49.31	54.00
Mean	57.47	55.97	54.29	50.80	50.72	51.06	46.93	

[a]$LSD_{0.05}$ for population means = 1.52; for MSC vs others = 2.21, and between others = 1.80; for plant population at MSC = 4.18; for plant population at same hybrid (others) = 3.42.

medium plant population (Table 48).

The overall means for the hybrids indicate that the male-sterile with ears covered had the highest IVDMD value for the stover (57.47%) which was similar to the third cycle of selection hybrid, but was significantly different from the others. The first cycle of selection for stalk strength had a significantly higher value than the synthetic variety, normal cytoplasm, and male-sterile, which were not significantly different. The prolific hybrid showed the least concentration of IVDMD of the stover (46.93%).

The means for the interactions show that IVDMD did not respond the same for all hybrids with increase in stand density. For instance, for the male-sterile with ears covered, the values decreased with increasing population. For others, like the first cycle of selection for stalk strength and male-sterile, population levels did not affect the digestibility significantly. All the remaining hybrids (C3, C0, N, and PR) showed a significantly greater IVDMD for the highest population level, but there was no difference between the low and medium population levels.

Interrelationships Between Variables

The partial correlation coefficients with the effects of hybrid and population removed are presented in Table 49.

Stalk strength was positively correlated with stalk

Table 49. Partial correlation coefficients within plant population levels and hybrids

	Variables							
	LH	D	V	ADF-S	ADL-S	ADF-R	ADL-R	ADF-P
LH		0.16*	0.66**	0.04	-0.02	0.22**	0.21**	0.07
D			0.79**	-0.06	-0.13*	0.03	-0.08	0.12
V				-0.04	-0.13*	0.12	0.03	0.14*
ADF-S					0.87**	0.75**	0.43**	0.75**
ADL-S						0.64**	0.46**	0.58**
ADF-R							0.60**	0.69**
ADL-R								0.31**
ADF-P								
ADL-P								
IVDMD-S								
IVDMD-R								
IVDMD-P								
SS								
SSS								
RTH								
SU								

Variables							
ADL-P	IVDMD-S	IVDMD-R	IVDMD-P	SS	SSS	RTH	SU
0.04	-0.04	-0.15*	-0.07	-0.17**	-0.34**	-0.30**	0.11
0.10	-0.04	-0.14*	-0.19**	0.22**	-0.32**	0.03	-0.08
0.11	-0.02	-0.15*	-0.20**	0.06	-0.42**	-0.16*	-0.01
0.53**	-0.94**	-0.75**	-0.61**	-0.30**	-0.23**	0.05	-0.48**
0.44**	-0.81**	-0.65**	-0.44**	-0.13*	-0.03	0.18**	-0.40**
0.53**	-0.72**	-0.83**	-0.57**	-0.20**	-0.20**	-0.03	-0.38**
0.31**	-0.39**	-0.50**	-0.21**	-0.04	0.00	0.01	-0.19**
0.86**	-0.75**	-0.73**	-0.89**	-0.33**	-0.35**	-0.08	-0.41**
	-0.55**	-0.58**	-0.82**	-0.22**	-0.23**	-0.06	-0.25**
		0.81**	0.69**	0.34**	0.29**	-0.02	0.47**
			0.69**	0.25**	0.28**	0.08	0.40**
				0.38**	0.41**	0.15	0.31**
					0.80**	0.52**	0.12
						0.52**	0.11
							-0.09

diameter, IVDMD of the whole internode, the rind, the pith, and also with rind thickness. In contrast, stalk strength was negatively correlated with length of the internode; ADF of the whole internode, the pith, and the rind; and ADL of the stalk and the pith.

Stalk diameter was negatively correlated with IVDMD of the rind and pith. Rind thickness was negatively correlated with length of the internode and volume, and positively correlated with ADL of the whole internode. The two variables which appeared to be least correlated with the other variables were stalk diameter and rind thickness. These two most independent variables were included in all the regression models. The third variable in each model was one of the quality variables which was highly correlated with stalk strength (IVDMD-P, IVDMD-S, ADF-P, ADF-S). The following four regressions were calculated for each plant population and harvest time across location, hybrid, and replication:

SS = a + b RTH + c IVDMD-P + d D

SS = a + b RTH + c IVDMD-S + d D

SS = a + b RTH + c ADF-P + d D

SS = a + b RTH + c ADF-S + d D

The greatest amount of the total sum of squares for each harvest and population level were explained by the following models:

Pop	Time	Regression equation	R^2
P1	T1	SS = -156.68 + 21.10** RTH + 1.32** IVDMD-P + 24.06** D	0.73
P2	T1	SS = -14.67 + 26.14** RTH - 0.93** ADF-P + 11.71* D	0.79
P3	T1	SS = -51.79 + 20.97** RTH + 0.27 IVDMD-P + 12.20** D	0.68
		SS = -43.98 + 23.59** RTH + 0.19 IVDMD-S + 11.98** D	0.68
P1	T2	SS = 11.67 + 40.72** RTH + 1.34** ADF-S + 8.86 D	0.81
P2	T2	SS = -60.03 + 39.65** RTH + 0.67** IVDMD-S - 0.44 D	0.71
		SS = 5.79 + 42.03** RTH - 0.80** ADF-S - 0.94 D	0.71
P3	T2	SS = -68.71 + 32.45** RTH + 0.37** IVDMD-S + 14.08* D	0.71

From these data, it is evident that rind thickness was a major component of stalk strength, and that these models *per se* explained a considerable amount of the total sum of squares.

Stover Dry Matter Yield

This variable was significantly affected ($p<0.01$) by plant populations and hybrids. The interactions were not significant (Table 2). The highest plant densities showed the largest value (10.3 tons ha^{-1}) for stover yield, but at the low and medium population levels, there was no significant difference (Table 50).

Table 50. Stover dry matter yield as affected by plant population and hybrid[a]

Plant population			Hybrid						
P1	P2	P3	MSC	C3	C1	CO	N	MS	PR
------------------------t ha^{-1}									
8.3	8.2	10.3	17.8	7.8	8.4	6.3	9.3	10.6	6.6

[a] $LSD_{0.05}$ for population = 1.3; for MSC vs others = 2.34; and between others = 1.91.

The male-sterile hybrid with ears covered showed the greatest value (17.8 tons ha^{-1}). Among the remaining hybrids, the male-sterile and the normal cytoplasm tended to have greater stover yields (10.6 and 9.3 tons ha^{-1}, respectively). The prolific hybrid and the synthetic variety had the lowest values (Figure 12).

Grain Yield

Location had a significant effect ($p<0.05$) on grain yield. Population and hybrid effects were highly significant ($p<0.01$) as well as the first-order interaction plant population x hybrid. All the other interactions were not significant (Table 2).

The average grain yield at Ames (49.17 quintals ha^{-1}) was significantly greater than at Nashua (43.19 quintals ha^{-1}) since $LSD_{0.05}$ = 4.76 quintals ha^{-1}. Plant population and

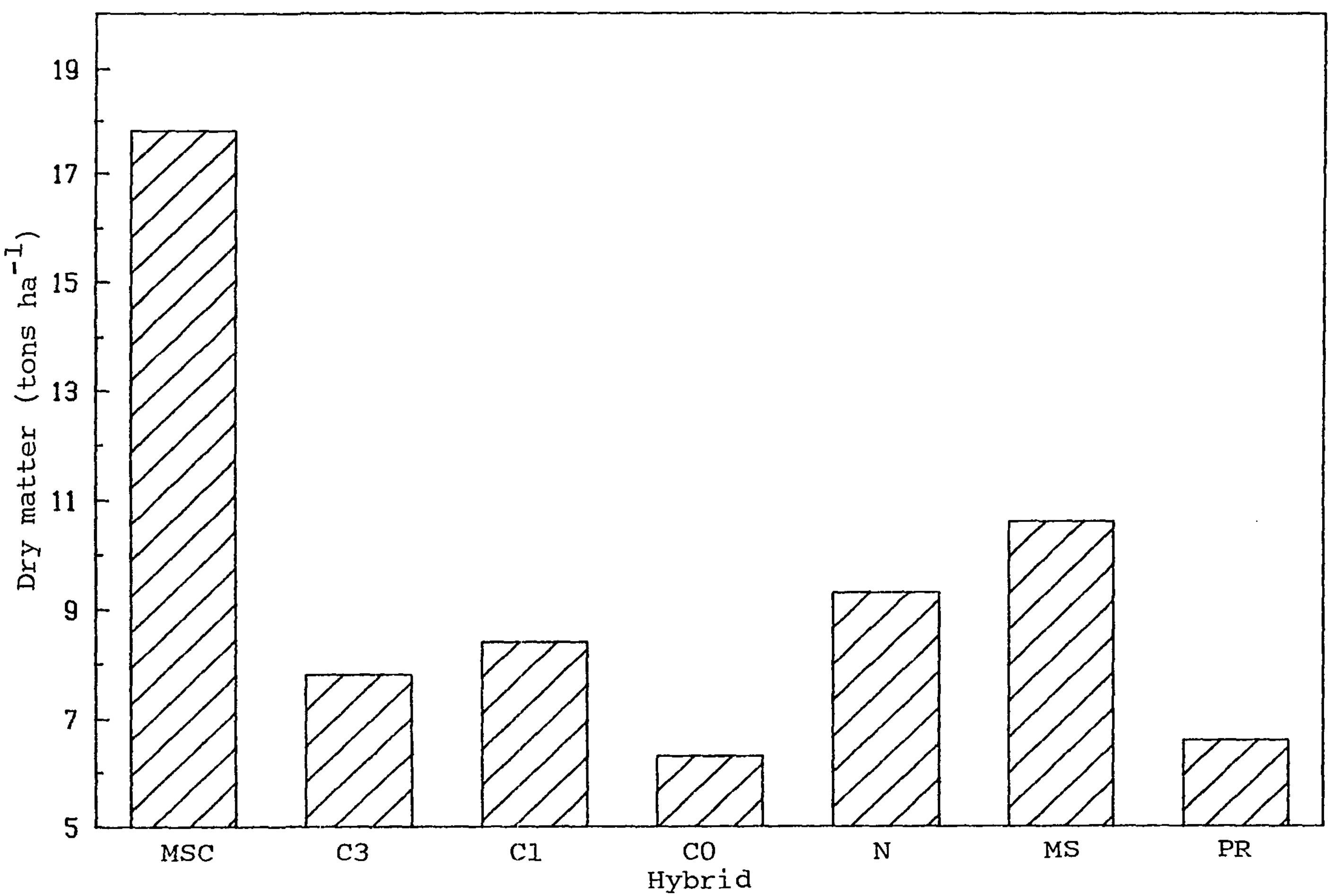


Figure 12. Stover dry matter yield as affected by hybrids

hybrid showed a highly significant effect ($p<0.01$) on grain yield and the first-order interaction plant population x hybrid was also highly significant.

Increasing plant population (32,123, 64,246, and 96,369 plants ha^{-1}) reduced grain yield significantly at all levels (Table 51), but since there was a significant interaction between hybrid and population, this did not happen equally with all the hybrids. For instance, the grain yield of the prolific hybrid tended to be less reduced than the other hybrids when plant population was increased from 64,246 to 96,369 plants ha^{-1} (Figure 13). Also, the yields of the male-sterile hybrid, first and third cycle of selection hybrids were reduced significantly just at the highest population level.

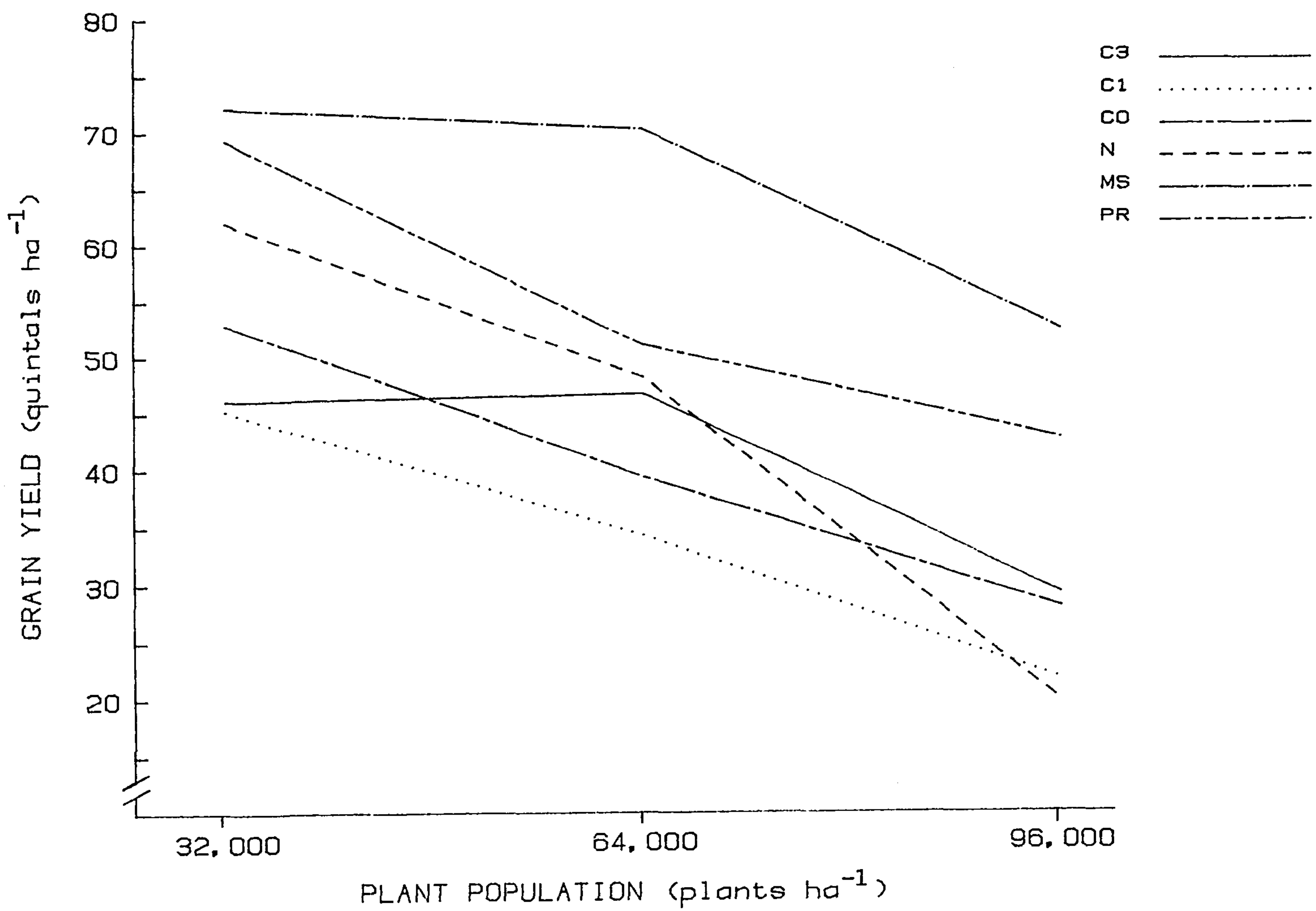
The overall means for the hybrids show that the greatest yielding hybrid was the male-sterile with an average yield of 64.93 quintals ha^{-1}. The prolific showed significantly lower yield (54.35 quintals ha^{-1}) than the male-sterile, but still had a greater yield than the remaining hybrids. The lowest yielding hybrid was the first cycle of selection for stalk strength hybrid with an average yield of 33.73 quintals ha^{-1}. The other three hybrids (normal cytoplasm, synthetic variety, and the third cycle of selection for stalk strength) were not significantly different. The means over the three replications for all the data are in Appendix Tables A3 to A24.

Table 51. Grain yield of corn as affected by plant population and hybrid[a]

Plant pop.	Hybrid C3	C1	C0	N	MS	PR	Mean
	--------	--------	--------	quintals ha^{-1}	--------	--------	
P1	46.13	45.21	52.94	61.98	72.15	69.25	57.95
P2	46.69	34.26	39.36	48.16	70.21	51.07	48.29
P3	29.15	21.72	27.95	19.84	52.42	42.72	32.30
Mean	40.66	33.73	40.08	43.33	64.93	54.35	

[a]$LSD_{0.05}$ for plant population = 4.22; for hybrid = 4.85; for plant population at same or different hybrid = 9.15.

Figure 13. Grain yield as affected by hybrids



GRAIN YIELD (quintals ha^{-1})
80
70
60
50
40
30
20
32,000
64,000
96,000
PLANT POPULATION (plants ha^{-1})
C3
C1
CO
N
MS
PR

DISCUSSION AND CONCLUSIONS

Stalk Strength

Previous literature has indicated the importance of rind thickness in explaining variation in stalk strength (Zuber and Grogan, 1956; Thompson, 1963; Cloninger et al., 1970). Another variable associated with stalk strength is sugar content of the stalk (Mortimore and Ward, 1964; Campbell, 1964; Esechie et al., 1977; Colbert et al., 1984). Rind thickness implies a strength factor, whereas sugar concentration implies a healthier stalk with more resistance to stalk pests. A possible strength aspect of sugar concentration is that the osmotic pressure of sugar increases turgor potential which could increase stalk strength. A third variable is fiber concentration, which has been reported to be positively associated with strength (Hunter and Dalbey, 1937; Magee, 1948; Murdy, 1960; Pinthus, 1973), but some recent studies have reported a negative relationship between stalk strength and fiber (Albrecht et al., 1983).

In this study, stalk strength of most of the hybrids decreased with increased population. The two morphological changes which were closely associated with decreased stalk strength were a smaller stalk diameter and a thinner rind. These two changes could logically explain the effect of population on stalk strength. Forage quality aspects such as percentage of fiber as measured by ADF and ADL decreased with increasing population which would agree with weaker stalks at higher populations. However, where percentage of ADF and ADL were expressed on a dry matter basis with the amount of sugar subtracted, there was no effect of population on ADF and ADL. The percentage of sugar in the stalk sap increased with increasing population which should have increased stalk strength at the higher populations. If sugar had an effect of increasing stalk strength in this study, its effect was overcome by the more dominant effects of decreased stalk diameter and rind thickness. In this study, a severely high temperature and moisture stress during late July and August caused large amounts of barrenness as population increased. Normally, stalk sugar decreases with increasing population until barrenness becomes a factor (Williams et al., 1968; Troyer and Rosenbrook, 1983). In the absence of stress, stalk strength may have decreased even more with increases in population than was found in this experiment.

Time of harvest affected stalk strength. At physiological maturity, the stalks were weaker than at the mid-silk stage for all hybrids except for the male-sterile hybrid with ears covered, which was stronger. In general, those hybrids and populations which produced the most grain had a large decrease in stalk strength with increased age, whereas those hybrids or populations with low grain yield did not decrease in stalk strength between the first and second harvests. Rind thickness decreased between harvests, but only at Ames; the effect of rind thickness as related to stalk strength was not clear. Changes in sugar content between harvests agreed well with changes in stalk strength. The prolific, male sterile and normal had a decrease in stalk strength between the two harvests of 10, 12, and 9 kg, respectively, and sugar decreased 0.8, 0.6, and 0.6%. The stalk strength and sugar percentage of the other hybrids changed little or increased between the first and second harvests.

Hybrids varied in stalk strength. The hybrids were selected to vary in stalk strength in the order listed in the tables with the male-sterile hybrid with ears covered as the strongest and the prolific as the weakest. Within the seven hybrids, there are logical comparisons. The synthetic, first cycle and third cycle hybrids were from a study where there had been selection for stalk strength and represent the C0, C1, and C3 cycles of selection for stalk strength, respectively. The male sterile, normal, and male-sterile hybrid with ears covered are another series with expected increase in stalk strength. These three hybrids had the same nuclear genes but differed from the normal hybrid by being male sterile but pollinated by pollen from the field or by being male sterile with ears covered to prevent grain formation. The normal and prolific compared a typical single-eared hybrid with a prolific hybrid with known tendency for stalk lodging.

Selection for stalk strength from the synthetic hybrid increased stalk strength from 25.3 to 29.5 during the first cycle to 34.9 kg by the third cycle, and there was a concomitant increase in rind thickness from 1.36 to 1.42 and 1.50 mm. There was no indication that stalk strength was related to sugar percentage. The stalk forage quality parameters of ADF and ADL definitely did not increase with stalk strength, but rather tended to decrease, and IVDMD increased.

The stalk strength of the series of prolific, male-sterile, normal, and male-sterile hybrid with ears covered increased from 29.7, 39.0, 38.2 to 56.5 kg, respectively, and in agreement, rind thickness increased from 1.47, 1.62, 1.64 to 1.85 mm; also sugar increased from 5.5, 6.4, 7.0 to 11.9% as stalk strength increased when compared across populations, harvests, and locations. The ADF and ADL values definitely decreased as stalk strength increased, even when adjusted for sugar. The IVDMD increased with increased stalk strength. Internode length and diameter of the hybrids were not related to stalk strength in this stalk-strength series or in the series with selection for stalk strength.

Stalk strength was expressed on both the basis of the force to break the stalk (kg) and force per unit area of the stalk (kg cm^{-2}). The treatments (hybrid, plant population, harvest, and location) affected the two stalk strength measurements very similarly. The F-values for the treatments and their interactions were almost identical for the two stalk strength measurements (from Table 1). Likewise, the partial correlation coefficients were very similar except for stalk diameter (Table 49). Stalk strength was positively correlated with diameter, whereas stalk strength per unit area was negatively correlated with diameter. The cause of opposite signs of the correlation was that force required for breakage was nearly linearly related to stalk diameter, but when force was divided by $\pi d^2/4$, the exponential effect of diameter resulted in a negative relationship between force per unit area and increasing stalk diameter.

Sugar concentration was largest at the highest population density level. This was due to a large percentage of barren plants. The male-sterile hybrid with ears covered showed the largest amount of sugars in the stalk as would be expected since no grain was formed. The prolific showed low amount of sugar in the stalk which is not surprising due to the large sink size.

Moisture in the stalk decreased as the sugar concentration increased, but this does not necessarily mean that the plants with more sugar were less turgid. In fact, the large concentration of sugar in the sap increases osmotic potential which normally increases the pressure potential or turgidity of the tissue.

Internode length was greatest in one of the weakest hybrids, which was the prolific, and one of the strongest hybrids showed the shorter internode. The effect of internode length on stalk strength might not have been evaluated by the machine used to measure stalk strength since the applied pressure was not at the nodes but at an equal distance from the middle of the internode. In the field, internode length might have some significance as reported by Thompson (1964).

Population density levels only affected significantly the internode length in the prolific hybrid which was shorter at the lowest population level. Diameter and volume were greatest in the prolific hybrid, and this is the opposite that should be expected if those variables were the major factors affecting stalk strength.

From these data, it seems that stalk strength is a complex phenomenon which is highly positively correlated with rind thickness. Even though the partial correlation coefficients do not show any significant correlation between stalk strength and sugar concentration, it does not seem that this variable should be ruled out as being partially responsible for stalk strength. The strongest hybrid was far stronger than the others, and the most noticeable differences between it and the other hybrids were rind thickness and sugar concentration in the sap. Sugars might help to keep plants healthier and more turgid for a longer period of time. Smaller diameter and lower rind thickness seemed to be the major factors responsible for reduced stalk strength at the highest plant densities. In this case, if just sugars accounted for stalk strength, the concentration should decrease. But, what happened was exactly the opposite, probably due to increased barrenness caused by the highest population level, according to Troyer and Rosenbrook (1983).

Stover Forage Quality

Histological studies on corn stalks by Hunter and Dalbey (1937), Magee (1948), and Murdy (1960) would indicate that strong stalk hybrids would be expected to have more cell wall material and, therefore, would be less digestible. Greater amounts of lignin and cellulose have often been reported as associated with lodging resistance. These structural materials would decrease forage quality. In this study, stalk strength seemed to be associated with improved forage quality, which is in agreement with what was reported by Albrecht et al. (1983).

Acid detergent fiber of the whole internode, rind and pith was significantly higher at Ames and was lower at higher population levels. Not all the hybrids were affected equally by plant density. This was more evident in the prolific hybrid, especially for ADF of the whole internode and pith, and may be the result of a very large sink. As a consequence, most of the TNC in the stalk may have been mobilized to the grain. The largest ADF values of the whole internode, pith, and rind were found in the hybrids which yielded the most grain (male sterile and prolific). The male-sterile hybrid with ears covered showed the lowest amount of ADF for the whole internode, rind, and pith, respectively, 33.41, 46.56, and 14.53%, which is not surprising considering the sugar content in the sap for that hybrid. Albrecht et al. (1983) reported values of ADF of the whole internode to decrease from 42.4% to 35.3% after selection for stalk strength. As would be expected, ADF of the whole internode, rind, and pith was largest at the second harvest at both locations. Within each population level and for most of the hybrids, except male-sterile with ears covered, when expressing ADF in percentage of dry matter from which the sugars have been subtracted, it was found that the prolific hybrid showed the largest value of ADF of the internode, but there was no significant difference between the other hybrids.

Acid detergent lignin of the whole internode, rind, and pith was higher at the second harvest. Increasing population density levels decreased ADL of the whole internode and pith for some of the hybrids, but did not significantly affect

ADL of the rind for most of the hybrids. The prolific hybrid showed the largest amount of ADL of the internode, rind, and pith. The male-sterile hybrid with ears covered showed the lowest values of ADL, especially for the whole internode and pith.

In vitro dry matter disappearance for the whole internode, rind, and pith, in contrast to what happened with ADF and ADL, was significantly higher for the first harvest. Increasing population increased the quality of the whole internode, rind, and pith for some hybrids. The male-sterile hybrid with ears covered had the greatest IVDMD value for the whole internode, rind, and pith, while the prolific hybrid showed the least values. Similar trends occurred with IVDMD of the stover as affected by harvests, population density, and hybrids. Therefore, the stover of the prolific hybrid had the poorest quality to use as a feed.

Stover and Grain yield

Stover dry matter yield was increased by population. These results are in agreement with what was reported by Tourbier and Rohweder (1983) and Bryant and Blaser (1968) concerning total dry matter yield. Other authors reported lower values of plant densities to reach maximum dry matter yield (Alexander et al., 1963; Alessi and Power, 1974). The greatest stover yields were found in the male-sterile with ears covered and the lowest yield was shown in the prolific hybrid.

Average grain yield was higher in Ames than at Nashua due to greater stress at that location. Increasing plant population reduced grain yields for most of the hybrids at all levels. The prolific hybrid though was not significantly affected because it is highly tolerant to population density. According to what was stated by Colville et al. (1964), Troyer and Rosenbrook (1983), Alexander et al. (1963), and Hoeffliger (1980), the highest population density used in this study (96,369 plants ha^{-1}) was too high for maximum grain yield. The intermediate level (69,246 plants ha^{-1}) should have been optimum for some genotypes and slightly too high for others, but the stress conditions which prevailed during flowering time, as indicated by the climatological data, also made the intermediate too high for maximum yields. Therefore, at that population density, the grain yields obtained were already in the descendent part of the yield response curve. The prolific hybrid was not so affected by population levels because it is more tolerant to greater population densities because these kind of hybrids adjust to population pressure by varying the number of ears per plant, with only slight ear weight changes and little or no whole plant barrenness as pointed out by Collins et al. (1965), Bauman (1959), Josephson (1961), and Hinkle and Garret (1961). The male-sterile hybrid and the third cycle of selection hybrid were affected significantly by plant density just at the highest population level. Male-sterility makes hybrids more tolerant to high plant population densities as reported by Chinwuba et al. (1961), Bruce et al. (1966), Meyer (1970), and Criswell et al. (1974). The male-sterile hybrid had the highest yield at each population level and compared with its fertile counterpart, it yielded 10, 22, and 32 quintals ha^{-1} more at the low, medium, and high populations, respectively. At the highest population, male-sterile yielded 26.4% more than the fertile counterpart. The second highest yielding hybrid at each population was the prolific. It was expected from the results of Albrecht et al. (1983) that the third cycle of selection hybrid would yield less than the first cycle, but it yielded more and was similar to the synthetic. Therefore, from these results, the effect of selection for stalk strength on grain yield was not clear and different from the results of Albrecht et al. (1983), Thompson (1982), and Davis and Crane (1976).

Conclusions

The conclusions of this study were as follows:

1. Stalk strength seems to be a complex phenomenon. From all the traits measured, rind thickness is by far the most closely associated with stalk strength. Sugars might

also contribute by keeping plants healthier and more turgid for a longer period of time. Decreasing stalk diameters as plant population level increased might also have accounted for the decrease in stalk strength with increasing plant densities.

2. The quality of the whole internode, rind, pith, and stover was not adversely affected by increasing stalk strength. In fact, percentage of ADF and ADL decreased in the stronger stalk hybrids while percentage IVDMD increased. The prolific hybrid had the least stover quality.

3. Stover yield was greatest in the male-sterile hybrid with ears covered and was least in the prolific hybrid.

4. There was no clear sacrifice in grain yield by increasing stalk strength, and male-sterility was responsible for the greatest yields under stress conditions. The prolific hybrid also produced relatively high yields.

LITERATURE CITED

Albrecht, K. A., M. J. Martin, W. A. Russell, W. F. Wedin, and D. R. Buxton. 1983. Forage quality of maize stalks after selection for stalk strength and stalk rot resistance. Proc. Forage and Grassland Conf. 1983: 146-147.

Alessi, J., and J. F. Power. 1974. Effects of plant population, row spacing, and relative maturity on dryland corn in the northern plains. I. Corn forage and grain yield. Agron. J. 66: 316-319.

Alexander, R. A., J. F. Hentges, Jr., W. K. Robertson, G. A. Barden, and J. T. McCall. 1963. Composition and digestibility of corn silages as affected by fertilizer rate and plant population. J. Anim. Sci. 22: 5-8.

Allard, R. W. 1960. Principles of plant breeding. John Wiley and Sons, Inc., New York.

Anderson, I. C. 1967. Plant characteristics that affect yield. Proc. Ann. Hybrid Corn Ind.-Res. Conf. 22: 71-73.

Baracco, P. N. 1961. Effects of row spacing and population levels on performance of four corn inbreds in single-cross hybrids. M.S. thesis. Library, Iowa State University, Ames, Iowa.

Barnes, R. F., L. D. Muller, L. F. Bauman, and V. F. Colenbrander. 1971. _In vitro_ dry matter disappearance of brown midrib mutants of maize (_Zea mays_ L.). J. Anim. Sci. 33: 881-884.

Barratt, D.H.P., and P. A. Peterson. 1977. Mitochondrial banding pattern difference in electrofocused polyacrylamide gels between male-sterile and nonsterile cytoplasm of maize. Maydica 22: 1-8.

Bauman, L. F. 1959. Environmental interactions with prolific hybrids. Proc. Ann. Hybrid Corn Ind.-Res. Conf. 14: 53-59.

Bratzler, J. W., T. B. King, and W. I. Thomas. 1965. Nutritive value of high-sugar corn silage. J. Anim. Sci. 24: 1218.

Bruce, R. R., J. O. Sanford, and D. L. Myhre. 1966. Soil water and nitrogen influence on growth and fruiting of a cytoplasmic male-sterile corn hybrid and its fertile counterpart. Agron. J. 58: 631-634.

Bryant, H. T., and R. E. Blaser. 1968. Plant constituents of an early and late corn hybrid as affected by row spacing and plant population. Agron. J. 60: 557-559.

Bunting, E. S. 1975. The question of grain content and forage quality in maize: Comparisons between isogenic fertile and sterile plants. J. Agric. Sci., Camb. 85: 455-463.

Bunting, E. S. 1976. Effects of grain formation on dry matter distribution and forage quality in maize. Expl. Agric. 12: 417-428.

Bunting, E. S., and L. A. Willey. 1959. The cultivation of maize for fodder and ensilage. II. The effect of changes in plant density. J. Agric. Sci. 52: 313-319.

Buren, L. L. 1970. Plant characteristics associated with barrenness in maize. Ph.D. dissertation. Library, Iowa State University. Ames, Iowa.

Campbell, C. M. 1964. Influence of seed formation of corn on accumulation of vegetative dry matter and stalk strength. Crop Sci. 4: 313-34.

Chinwuba, P. M., C. O. Grogan, and M. S. Zuber. 1961. Interaction of detasseling, sterility, and spacing on yields of maize hybrids. Crop Sci. 1: 279-280.

Cloninger, F. D., M. S. Zuber, O. H. Calvert, and P. J. Loesch. 1970. Methods of evaluating stalk quality in corn. Phytopathology 60: 295-300.

Colbert, T. R., L. L. Darrah, and M. S. Zuber. 1984. Effect of recurrent selection for stalk crushing strength on agronomic characteristics and soluble stalk solids in maize. Crop Sci. 24: 473-478.

Collins, W. K., W. A. Russell, and S. A. Eberhart. 1965. Performance of two-ear type of Corn Belt maize. Crop Sci. 5: 113-116.

Colville, W. L., and G. P. McGill. 1962. Effect of rate and method of planting on several plant characters and yield of irrigated corn. Agron. J. 54: 235-238.

Colville, W. L., D. P. McGill, P. Grubouski, and P. Ehlers. 1964. Influence of plant population, hybrid and productivity level on irrigated corn production. Agron. J. 56: 332-335.

Criswell, J. G., D. J. Hume, and J. W. Tanner. 1974. Effect of cytoplasmic male-sterility on accumulation and translocation of ^{14}C-labelled assimilates in corn. Crop Sci. 14: 252-254.

Cummins, D. G., and M. E. McCullough. 1971. Comparison of male-sterile and male-fertile corn for silage. Agron. J. 63: 46-47.

Davis, Stephen M., and Paul C. Crane. 1976. Recurrent selection for rind thickness in maize and its relationship with yield, lodging, and other plant characteristics. Crop Sci. 16: 53-55.

Daynard, T. B., V. S. Baron, and M. Tollenaar. 1979. Points of current interest in studies of the physiology of maize plant. p. 205-215. In E. S. Bunting (ed.) Production and utilization of maize crop. Proceedings of the 1st European Maize Congress. The Hereward and Stourdale Press, Cambridge, England.

Dungan, G. H., A. L. Lang, and J. W. Pendleton. 1958. Corn plant population in relation to soil productivity. Crop Sci. 10: 435-473.

Durrell, L. W. 1925. Preliminary study of fungus action as a cause of down corn. Phytopathology 15: 146-154.

Duvick, Donald N. 1958. Yields and other agronomic characteristics of cytoplasmically pollen sterile corn hybrids, compared to their normal counterparts. Agron. J. 50: 121-125.

El-Lakany, M. A. 1970. Characterization of maize inbreds in test crosses for plant and ear characters and yield at varying plant densities and effectiveness of selection in successive generations of inbred progenies for improvement of hybrid yields. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

El-Lakany, M. A., and W. A. Russell. 1971. Relationship of maize characters with yield in test crosses of inbreds at different plant densities. Crop Sci. 11: 698-701.

Enyinnaya, Anosike M. 1980. Relationships between grain yield and growth rates of plant parts as influenced by male sterile cytoplasms, plant densities, and hybrids in corn (Zea mays L.). Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Esechie, H. A., J. W. Maranville, and W. M. Ross. 1977. Relationship of stalk morphology and chemical composition to lodging resistance in sorghum. Crop Sci. 17: 609-612.

Flavell, Richard. 1974. A model for the mechanism of cytoplasmic male sterility in plants with special reference to maize. Plant Sci. Letters 3(4) 259-263.

Fleming, A. A. 1975. Effects of male cytoplasm inheritance in hybrid maize. Crop Sci. 15(4): 570-573.

Goering, H. K., and P. I. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures, and some cations). Agric. Handbook No. 379. USDA, ARS, Washington, D.C.

Gracen, V. E., and C. O. Grogan. 1974. Diversity and suitability for hybrid production of different sources of cytoplasmic male sterility in maize. Agron. J. 66: 654-657.

Grogan, C. O. 1956. Detasseling response in corn. Agron. J. 48: 247-249.

Grogan, C. O., C. A. Francis, and P. A. Sarvella. 1971. Effects of cytoplasmic male sterility and restoring factors on yield and morphology in inbred and hybrid maize (Zea mays L.). Crop Sci. 11: 295-297.

Grogan, C. O., P. Sarvella, J. O. Sanford, and H. V. Jordan. 1965. Influence of cytoplasmic male sterility on dry matter accumulation in maize (Zea mays L.). Crop Sci. 5: 365-367.

Hinkle, D. A., and J. D. Garret. 1961. Corn fertilizer and spacing experiments. Arkansas Agric. Exp. Stn. Bull. 635.

Hoeffliger, M. A. 1980. Yield and nutritive value of corn for silage as affected by maturity, hybrid and plant population. M.S. thesis. Library, Iowa State University, Ames, Iowa.

Holechek, J. L., M. Vavra, and R. D. Pieper. 1982. Methods for determining the nutritive quality of range ruminant diets: A review. J. Anim. Sci. 54: 363-376.

Hooker, A. L., D. R. Smith, S. M. Lim, and J. B. Beckett. 1970. Reaction of corn seedlings with male sterile cytoplasm to Helminthosporium maydis. Plant Dis. Rep. 54: 708-712.

Hunter, James W., and Nora E. Dalbey. 1937. A histological study of stalk-breaking in maize. Am. J. Bot. 24: 492-494.

Jenkins, M. T. 1930. Experiments on stiffness of stalk. Iowa Agric. Exp. Stn. Annual Rep. 1930: 51.

Jenkins, M. T., and W. G. Gaessler. 1934. Correlation between composition and stiffness of stalk in the corn plant. Iowa Agric. Exp. Stn. Annual Rep. 1934: 108.

Jorgensen, N. A., and W. T. Howard. 1982. Forages in dairy enterprises during the 80's. Proc. 6th Wisconsin Forage Council Symposium, Appleton, Wisconsin.

Josephson, L. M. 1961. Combining prolificacy and earliness. Ann. Hybrid Corn Industry Research Conf. Proc. 16: 45-52.

Lechtenberg, V. L., L. D. Muller, L. F. Bauman, C. L. Rhyckerd, and R. F. Barnes. 1972. Laboratory and in vitro evaluation of inbred and F_2 populations of brown midrib mutants of Zea mays L. Agron. J. 64: 657-660.

Levings, C. S. III, and D. R. Pring. 1976. Biochemical basis of normal and male sterile cytoplasms of corn. Proc. 31st Annual Corn and Sorghum Research Conference 1976: 110-117.

Lim, S. M., A. L. Hooker, J. G. Kinsey, and D. R. Smith. 1974. Comparative grain yields of corn hybrids in normal and in Texas male-sterile cytoplasm (cms-T) infected with Helminthosporium maydis race T and disease components of cms-T corn hybrids. Crop Sci. 14: 190-195.

Magee, Jean Anne. 1948. Histological structure of the stem of Zea mays in relation to stiffness of stalk. Iowa State College J. Sci. 22: 257-268.

Marten, G. C. 1980. Chemical, in vitro, and nylon bag procedures for evaluating forage in the U.S.A. In J. L. Wheeler and R. D. Mochrie (eds.) Forage evaluation: Concepts and techniques. Commonwealth Scientific and Industrial Research Organization, East Melbourne, Australia.

Marten, G. C., and R. F. Barnes. 1980. Prediction of energy digestibility of forages with *in vitro* rumen fermentation and fungal enzyme systems. p. 61-71. *In* Proc. Intern. Workshop on Standardization Anal. Meth. Feeds, Ottawa, Canada.

Marten, G. C., and P. M. Westerberg. 1972. Maize fodder influence of barrenness on yield and quality. Crop Sci. 12: 367-369.

Marten, G. C., R. D. Goodrich, A. R. Schmid, J. C. Meiske, R. M. Jordan, and J. C. Linn. 1975. Evaluation of laboratory methods for determining quality of corn and sorghum silages. II. Chemical methods for predicting *in vivo* digestibility. Agron. J. 67: 247.

Martin, M. J., and W. A. Russell. 1984. Response of a maize synthetic to recurrent selection for stalk quality. Crop Sci. 24: 331-337.

Meyer, D. W. 1970. Use of male-sterility for increasing the population tolerance of corn (*Zea mays* L.). Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Mortimore, C. G., and S. M. Ward. 1964. Root and stalk rot of corn in southwestern Ontario. III. Sugar levels as a measure of plant vigor and resistance. Can. J. Plant Sci. 44: 451-457.

Moss, Dale N. 1962. Photosynthesis and barrenness. Crop Sci. 2: 366-367.

Muller, L. D., R. F. Barnes, L. F. Bauman, and V. F. Colenbrander. 1971. Variation in lignin and other structural components of brown midrib mutants of maize. Crop Sci. 11: 413-415.

Murdy, W. H. 1960. The strengthening system in the stem of maize. Ann. Missouri Bot. Gard. 47: 205-206.

Noble, S. W. 1973. Performance of Scms, Ccms, and normal cytoplasm hybrids of corn (*Zea mays* L.). Am. Soc. Agron. Abstr. 1973: 11.

Norden, A. J. 1961. Response of field corn varieties to plant population and planting dates on flatwood soils. Soil Crop Sci. Soc. Florida Proc. 21: 213-220.

Ortiz-Cereceras, J. 1967. Influence of plant population levels on the correlation among agronomic characters of S_2 lines of maize and their test-crosses. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Perry, T. W., and D. M. Caldwell. 1969. Comparative nutritive value of silages made from high-sugar male-sterile hybrid corn and regular starchy corn. J. Dairy Sci. 52: 1119-1121.

Pinthus, M. J. 1973. Lodging in wheat and oats: The phenomenon, its causes, and preventive measures. Adv. Agron. 25: 209-263.

Rogers, J. S., and J. R. Edwardson. 1952. The utilization of cytoplasm male-sterile inbreds in the production of corn hybrids. Agron. J. 44: 8-13.

Rossman, E. C., and R. L. Cook. 1966. Seed preparation and date, rate and pattern of planting. p. 53-102. In W. H. Pierre, S. R. Aldrich, and W. P. Martin (eds.) Advances in corn production, principles and practices. Iowa State University Press, Ames, Iowa.

Rouse, G. 1978. Silage for beef cattle. Iowa Coop. Ext. Serv. Pm 417e.

Rutger, J. N., and L. V. Crowder. 1967. Effect of high plant density on silage and grain yields of six corn hybrids. Crop Sci. 7: 182-184.

Sanford, J. O., C. O. Grogan, H. V. Jordan, and P. A. Sarvella. 1965. Influence of male-sterility on nitrogen utilization in corn, Zea mays L. Agron. J. 57: 580-583.

Sarvella, Patricia, and C. O. Grogan. 1976. Stem morphology and anatomy in Zea mays L. as influenced by cytoplasmic male sterility and restorer genes. Can. J. Plant Sci. 56: 249-255.

Scheifele, G. L. 1970. Cytoplasmically inherited susceptibility to diseases as related to cytoplasmically controlled pollen sterility in maize. 25th Annual Corn and Sorghum Research Conference Proc. 1970: 110-138.

Scheifele, G. L., W. Whitehead, and C. Rowe. 1970. Increased susceptibility to southern leaf spot Helminthosporium maydis in inbred lines and hybrids of maize with Texas male sterile cytoplasm. Plant Dis. Rep. 54: 501-503.

Schwanke, R. 1965. Alteration of reproductive attributes of corn varieties by population and detasseling. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Service, J. 1972. Statistical analyses system (SAS). Department of Statistics, North Carolina State University, Raleigh, North Carolina.

Smith, D. R., A. L. Hooker, S. M. Lim, and J. B. Beckett. 1971. Disease reaction of thirty sources of cytoplasmic male-sterile corn to Helminthosporium maydis Rate T. Crop Sci. 11: 772-773.

Snedecor, G. W., and W. G. Cochran. 1975. Statistical methods. 6th edition. Iowa State Press, Ames, Iowa.

Stake, P. E., M. J. Owens, D. J. Schingoethe, and H. H. Voelker. 1973. Comparative feeding value of high-sugar male sterile and regular dent corn silages. J. Dairy Sci. 56: 1439-1444.

Stephen, M. D., and P. L. Crane. 1976. Recurrent selection for rind thickness in maize and its relationship with yield, lodging, and other plant characteristics. Crop Sci. 16: 53-55.

Struik, P. C. 1982. Production pattern, chemical composition and digestibility of forage maize (Zea mays L.). Mededeling 64: 1-28.

Tatum, L. A. 1971. Southern corn leaf blight epidemic. Science 171: 1113-1116.

Thompson, D. L. 1963. Stalk strength of corn as measured by crushing strength and rind thickness. Crop Sci. 3: 323-329.

Thompson, D. L. 1964. Comparative strength of corn stalk internodes. Crop Sci. 4: 384-386.

Thompson, D. L. 1982. Grain yield of two synthetics of corn after seven cycles of selection for lodging resistance. Crop Sci. 22: 1207-1210.

Tourbier, Bruce, and Dwayne A. Rohweder. 1983. Effect of stage of maturity, corn hybrid type, and population on corn silage moisture and quality. Proc. Forage and Grassland Conference 1983: 153-158.

Troyer, A. F., and R. W. Rosenbrook. 1983. Utility of higher plant densities for corn performance testing. Crop Sci. 23: 863-867.

Undersander, D. J., L. F. Bauman, V. L. Lechtenberg, and M. S. Zuber. 1977. Effect of cyclic selection for high and low crushing strength on rind, pith, and whole stalk composition in corn. Crop Sci. 17: 732-734.

Van Soest, P. J. 1982. Nutritional ecology of the ruminant. O and B Books, Inc., Corvallis, Oregon.

Van Soest, P. J., and J. B. Robertson. 1980. Systems of analyses for evaluating fibrous feeds. p. 49-60. In Proc. Intern. Workshop on Standardization Anal. Meth. Feeds, Ottawa, Canada.

Vincent, G. B., and D. G. Woolley. 1972. Effect of moisture stress at different stages of growth: II. Cytoplasmic male-sterile corn. Agron. J. 64: 599-602.

Ward, J. K. 1978. Utilization of corn and grain sorghum residues in beef cow forage systems. J. Anim. Sci. 46: 831-840.

Warren, J. A. 1963. Use of empirical equations to describe the effcts of plant density on the yield of corn and the application of such equations to variety evaluation. Crop Sci. 3: 197-201.

Wilkinson, J. M., and R. H. Phipps. 1979. The development of plant components and their effects on composition of fresh and ensiled forage maize. J. Agric. Sci., Camb. 92: 485-491.

Williams, W. A., R. S. Loomis, W. G. Duncan, A. Dovrat, and F. Nunez A. 1968. Canopy architecture at various population densities and the growth and grain yield of corn. Crop Sci. 8: 299-303.

Wolf, E. A., and W. B. Howard. 1957. Effect of plant spacing on plant and ear characteristics of a single and double eared sweet corn hybrid. Florida State Hort. Soc. Proc. 1957: 70-92.

Woolley, D. G., N. P. Baracco, and W. A. Russell. 1962. Performance of four corn hybrids in single-cross hybrids as influenced by plant density and spacing patterns. Crop Sci. 2: 441-444.

Zuber, M. S. 1973. Evaluation of progress in selection for stalk quality. p. 110-122. In Proc. 28th Annual Corn and Sorghum Research Conference. American Seed Trade Association, Washington, D.C.

Zuber, M. S., and C. O. Grogan. 1956. Rate of planting studies with corn. Missouri Agric. Exp. Stn. Res. Bull. 610.

Zuber, M. S., and C. O. Grogan. 1961. A new technique for measuring stalk strength in corn. Crop Sci. 1: 378-380.

Zuber, M. S., C. O. Grogan, and O. V. Singleton. 1960. Rate of planting studies with prolific and single-ear hybrids. Missouri Agric. Exp. Stn. Bull. 737.

ACKNOWLEDGMENTS

I wish to express my sincere gratitude to Dr. W. F. Wedin, my major professor, and to Dr. I. C. Anderson, my co-major professor, for their guidance, suggestions, and support during my program of study. I am also grateful to Dr. C. A. Martins Portas, former head of the Department of Agronomy at Evora University, Portugal, for his endeavor in helping me to obtain a leave to pursue graduate studies. Thanks are extended to Drs. N. R. Lersten, D. R. Buxton, I. T. Carlson, and J. R. George for serving on my committee.

My appreciation goes to my sons Luis and David for the motivation they gave me toward reaching this achievement, and to the family, including my husband Antonio, for caring for my sons during part of the time that I was away from home. I also want to give thanks to my graduate fellows and friends for the encouragement and good humor which made my life easier.

For the financial support, acknowledgment is given to Evora University, Agency for International Development, and Iowa State University during the last part of my program of study, without which I would not have been able to finish.

APPENDIX

Table A1. Total monthly rainfall and average monthly temperatures at the Ames Agronomy and Agricultural Engineering Research Center, 1983

Month	Rainfall, cm		Temperature, °C	
	Actual	Dev. from normal	Actual	Dev. from normal
April	8.0	-0.6	6.4	-3.3
May	15.8	4.7	13.7	-2.5
June	23.2	10.2	21.7	0.5
July	9.7	1.0	25.1	1.8
August	10.7	0.8	25.8	3.8
September	8.1	-0.1	18.7	1.2
October	15.9	10.0	11.2	-0.4

Table A2. Total monthly rainfall and average monthly temperatures at the Northeast Iowa Research Center, Nashua, 1983

Month	Rainfall, cm		Temperature, °C	
	Actual at the Center	Dev. from normal, Charles City	Actual at the Center	Dev. from normal, Charles City
April	6.3	-2.2	5.6	-3.1
May	26.1	16.6	12.5	-3.0
June	17.8	5.9	20.6	0
July	8.5	-2.2	24.1	1.3
August	5.9	-4.8	24.2	2.5
September	25.5	16.4	17.1	0.2
October	7.2	1.3	9.7	-1.1

Table A3. Stalk strength

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			kg						
L1	T1	P1	72.9	56.1	45.4	40.9	67.0	72.0	49.3
		P2	56.3	31.0	30.9	23.6	41.8	41.0	31.5
		P3	30.3	22.9	23.2	18.3	24.7	28.5	31.6
L1	T2	P1	76.9	42.5	34.1	33.4	45.6	47.2	26.3
		P2	44.6	25.9	26.2	21.9	30.3	26.0	20.9
		P3	37.4	24.4	19.8	15.7	22.7	20.1	17.9
L2	T1	P1	82.9	54.8	39.2	34.1	61.6	66.4	42.8
		P2	50.7	29.8	24.2	23.2	36.6	36.5	29.4
		P3	34.2	27.1	22.2	15.1	25.6	27.2	23.5
L2	T2	P1	87.6	48.6	41.5	34.8	44.8	46.0	32.1
		P2	58.1	27.7	24.7	23.9	31.5	28.8	28.0
		P3	45.7	27.7	23.2	19.1	26.8	28.0	23.6

Table A4. Stalk strength per unit of area

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	Pr
			$kg\ cm^{-2}$						
L1	T1	P1	13.1	10.9	7.6	7.0	11.7	11.9	6.4
		P2	12.2	7.7	7.3	6.2	9.1	9.0	6.1
		P3	8.3	6.4	6.2	6.2	7.3	7.7	7.3
L1	T2	P1	12.4	9.3	6.1	6.3	7.9	7.4	3.7
		P2	10.7	5.7	6.5	5.1	6.3	5.9	4.1
		P3	9.1	6.7	5.5	5.7	6.3	5.6	4.5
L2	T1	P1	13.2	9.5	6.0	6.0	9.4	10.2	5.6
		P2	10.4	7.9	5.4	5.3	8.1	8.4	5.6
		P3	8.7	7.4	5.2	4.8	7.4	7.8	5.2
L2	T2	P1	14.2	8.6	6.9	5.8	7.2	7.5	4.2
		P2	12.9	7.0	5.4	5.4	6.8	6.6	5.2
		P3	10.5	7.2	5.7	5.5	7.7	7.2	5.1

Table A5. Rind thickness

Loc	Har	Pop	Hybrid						
			MSC	C3	C1	C0	N	MS	PR
			mm						
L1	T1	P1	2.4	2.1	1.8	1.5	2.2	2.2	1.8
		P2	2.1	1.5	1.4	1.5	1.7	1.8	1.5
		P3	1.6	1.3	1.4	1.2	1.4	1.5	1.6
L1	T2	P1	2.0	1.7	1.5	1.7	1.9	1.9	1.6
		P2	1.5	1.4	1.5	1.3	1.6	1.4	1.4
		P3	1.5	1.2	1.2	1.0	1.3	1.4	1.2
L2	T1	P1	2.5	1.7	1.5	1.5	1.9	1.9	1.6
		P2	1.7	1.4	1.3	1.3	1.5	1.5	1.4
		P3	1.5	1.3	1.3	1.1	1.4	1.3	1.3
L2	T2	P1	2.1	1.6	1.6	1.5	1.8	1.7	1.5
		P2	1.7	1.4	1.3	1.3	1.6	1.6	1.4
		P3	1.5	1.4	1.3	1.3	1.3	1.3	1.3

Table A6. Sugar concentration in the sap

Loc	Har	Pop	Hybrid						
			MSC	C3	C1	C0	N	MS	PR
			%						
L1	T1	P1	9.96	5.92	6.28	5.28	5.43	5.48	5.18
		P2	10.86	4.41	5.39	6.54	6.75	5.34	4.75
		P3	7.94	5.90	6.31	6.03	7.81	6.96	4.90
L1	T1	P1	13.47	6.24	4.56	4.49	4.75	5.13	4.31
		P2	12.96	6.75	6.77	7.45	6.58	6.60	4.56
		P3	12.92	8.56	8.32	7.62	8.09	7.35	8.28
L2	T1	P1	12.37	6.37	6.71	6.43	6.18	6.92	6.13
		P2	11.56	6.67	7.03	6.20	7.05	6.96	7.00
		P3	11.60	7.37	9.34	8.24	10.77	8.28	7.41
L2	T1	P1	14.64	6.52	8.83	4.62	5.15	3.83	3.28
		P2	12.05	5.75	6.65	5.94	5.18	6.20	5.58
		P3	12.71	7.34	7.75	9.60	10.33	7.24	4.58

Table A7. Stalk moisture

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			----	----	----	%	----	----	----
L1	T1	P1	77.45	83.07	84.19	84.27	82.73	82.73	86.34
		P2	78.29	85.35	84.65	82.39	83.98	83.33	85.36
		P3	80.44	85.29	83.25	83.02	81.04	83.38	85.12
L2	T1	P1	76.10	83.71	83.58	84.06	83.61	82.30	85.02
		P2	77.67	84.05	83.39	84.11	82.11	82.02	83.28
		P3	77.82	83.21	82.10	80.56	80.00	83.08	82.90
L2	T2	P1	75.57	84.08	84.39	84.40	84.11	84.77	83.71
		P2	76.44	84.24	82.98	83.30	84.07	82.11	84.88
		P3	76.75	82.93	82.89	79.35	78.50	82.66	85.34

Table A8. Length of the internode

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			----	----	----	cm	----	----	----
L1	T1	P1	13.5	12.4	12.0	12.6	12.5	12.9	13.5
		P2	11.5	11.9	11.6	12.8	11.4	12.1	14.9
		P3	12.3	12.6	13.5	11.6	11.7	11.6	13.9
L1	T2	P1	14.7	13.9	14.0	13.7	13.6	15.0	14.4
		P2	13.9	14.2	14.7	13.8	12.9	13.9	16.7
		P3	13.3	13.0	14.4	13.4	12.8	12.9	17.0
L2	T1	P1	13.2	13.8	13.6	13.6	13.7	13.6	14.8
		P2	14.0	13.1	14.4	14.1	12.8	13.6	15.8
		P3	13.7	14.2	14.5	13.1	12.0	13.4	16.1
L2	T2	P1	14.1	14.2	13.1	13.0	13.6	13.6	15.5
		P2	13.8	13.1	14.5	13.5	12.9	13.4	17.2
		P3	14.6	14.9	15.1	13.4	11.6	13.9	15.9

Table A9. Diameter of the internode

Loc	Har	Pop	MSC	C3	C1	C0	N	MS	PR
			Hybrid						
			cm						
L1	T1	P1	2.7	2.6	2.8	2.7	2.7	2.8	3.1
		P2	2.4	2.3	2.4	2.2	2.4	2.4	2.6
		P3	2.2	2.1	2.2	1.9	2.1	2.2	2.4
L1	T2	P1	2.8	2.4	2.7	2.6	2.7	2.8	3.0
		P2	2.3	2.4	2.3	2.3	2.5	2.4	2.5
		P3	2.3	2.2	2.1	1.9	2.1	2.1	2.3
L2	T1	P1	2.8	2.7	2.9	2.7	2.9	2.9	3.1
		P2	2.5	2.2	2.4	2.4	2.4	2.4	2.6
		P3	2.2	2.2	2.3	2.0	2.1	2.1	2.4
L2	T2	P1	2.8	2.7	2.7	2.8	2.8	2.8	3.1
		P2	2.4	2.2	2.4	2.4	2.4	2.4	2.6
		P3	2.4	2.2	2.3	2.1	2.1	2.2	2.4

Table A10. Volume of the internode

Loc	Har	Pop	MSC	C3	C1	C0	N	MS	PR
			Hybrid						
			cm^3						
L1	T1	P1	76.3	65.1	75.0	74.5	75.6	78.4	104.0
		P2	53.9	48.4	51.6	50.4	55.5	55.9	78.1
		P3	45.3	45.4	51.4	35.2	39.6	43.1	72.4
L1	T2	P1	91.3	64.8	80.9	73.4	81.2	96.0	101.0
		P2	56.4	64.5	62.0	60.2	61.7	61.4	84.9
		P3	54.8	47.4	52.2	38.8	46.1	46.7	67.3
L2	T1	P1	83.1	81.0	88.5	77.2	90.5	89.2	114.2
		P2	68.4	50.8	65.8	61.4	58.4	59.9	83.7
		P3	54.3	51.8	61.8	41.9	42.6	47.4	72.9
L2	T2	P1	87.0	80.2	78.3	79.0	86.4	83.7	117.3
		P2	63.8	52.6	66.5	59.6	60.4	59.4	92.9
		P3	64.3	57.3	61.1	46.4	40.8	54.1	73.6

Table A11. Acid detergent fiber of the whole internode

Loc	Har	Pop	MSC	C3	C1	C0	N	MS	PR
			Hybrid						
			%						
L1	T1	P1	35.72	40.35	40.58	43.61	43.07	42.20	47.69
		P2	36.08	38.56	41.02	42.18	42.80	42.17	48.63
		P3	35.54	37.66	39.87	37.15	36.14	40.50	47.62
L1	T2	P1	33.34	43.01	44.93	46.07	48.24	48.32	56.48
		P2	32.56	45.43	40.81	46.23	45.89	41.59	48.11
		P3	30.49	35.14	39.96	39.82	39.16	45.55	47.23
L2	T1	P1	32.98	35.12	36.14	40.13	40.26	39.06	43.26
		P2	32.98	35.41	34.25	38.26	36.20	38.73	39.06
		P3	32.51	36.17	31.97	33.42	34.05	34.57	38.93
L2	T2	P1	33.98	37.84	40.87	45.96	50.79	52.03	52.89
		P2	33.57	41.48	40.88	44.42	48.08	49.59	47.35
		P3	31.20	37.86	32.01	36.94	30.28	41.81	49.47

Table A12. Acid detergent fiber of the whole internode in percent of dry matter from which sugars had been subtracted

Loc	Har	Pop	MSC	C3	C1	C0	N	MS	PR
			Hybrid						
			%						
L1	T1	P1	54.36	56.95	60.57	60.92	58.07	47.24	74.21
		P2	60.58	51.99	58.99	60.91	67.01	57.70	67.85
		P3	52.92	56.98	58.06	52.64	54.47	63.03	66.52
L2	T1	P1	54.38	52.35	54.89	60.85	59.11	57.76	69.70
		P2	55.17	54.67	53.36	57.38	53.55	57.15	59.90
		P3	54.99	56.98	56.80	51.03	60.17	63.34	60.42
L2	T2	P1	62.17	58.50	84.34	61.26	69.62	66.14	64.05
		P2	55.16	60.34	60.09	64.79	66.03	68.56	69.02
		P3	53.88	58.03	51.19	60.23	49.61	63.71	67.06

Table A13. Acid detergent fiber of the rind

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			--------------	-----------	-----------	%	-----------	-----------	--------------
L1	T1	P1	47.55	49.82	49.32	50.08	52.32	53.35	54.66
		P2	44.33	48.04	47.90	49.53	52.68	49.10	55.53
		P3	46.55	47.49	49.81	46.30	46.06	48.52	56.92
L1	T2	P1	48.65	51.58	52.57	53.73	55.51	57.58	61.61
		P2	46.90	51.96	52.89	51.16	54.27	53.75	59.97
		P3	44.78	48.14	48.89	46.87	50.09	55.03	55.85
L2	T1	P1	47.39	48.47	48.75	46.86	54.02	51.82	55.65
		P2	46.62	47.54	44.31	47.73	50.35	51.63	51.87
		P3	46.08	47.60	41.52	44.77	44.26	49.35	52.19
L2	T2	P1	47.45	51.08	52.66	54.75	57.40	60.07	61.41
		P2	47.19	52.44	52.73	53.34	56.54	56.99	59.48
		P3	45.21	49.46	43.79	47.36	43.90	47.90	60.33

Table A14. Acid detergent fiber of the pith

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			--------------	-----------	-----------	%	-----------	-----------	--------------
L1	T1	P1	14.36	21.95	23.78	27.16	22.20	22.36	30.89
		P2	14.56	22.60	22.65	23.95	22.95	22.21	27.80
		P3	15.95	22.48	20.58	21.97	16.27	21.11	27.37
L1	T2	P1	16.45	23.83	27.95	29.24	28.87	31.41	40.28
		P2	14.43	23.59	22.02	29.38	26.04	23.89	35.26
		P3	13.34	28.39	20.91	21.63	20.94	24.95	26.33
L2	T1	P1	13.44	18.99	19.91	26.06	22.26	19.21	26.48
		P2	13.68	19.42	18.90	22.27	16.64	19.37	20.41
		P3	12.98	17.85	18.26	17.74	14.91	16.40	18.76
L2	T2	P1	16.86	22.39	28.03	32.82	34.37	35.18	39.38
		P2	13.96	25.64	27.07	29.91	30.84	30.97	28.52
		P3	14.34	20.84	19.28	22.02	17.42	22.95	33.90

Table A15. Acid detergent lignin of the whole internode

Loc	Har	Pop	MSC	C3	C1	CO	N	MS	PR
			Hybrid						
			%						
L1	T1	P1	5.99	5.78	6.36	6.81	6.37	6.30	6.36
		P2	6.07	5.50	5.92	5.72	6.26	6.86	7.61
		P3	5.49	5.06	5.08	5.19	5.63	6.13	9.15
L1	T2	P1	5.69	5.96	6.38	6.83	7.53	6.96	8.76
		P2	4.54	6.64	5.75	6.87	7.12	5.87	7.64
		P3	4.53	4.62	5.63	5.57	5.51	6.99	8.18
L2	T1	P1	4.49	4.16	4.89	5.36	5.40	5.37	5.91
		P2	4.34	4.27	4.55	5.10	4.81	5.34	5.79
		P3	4.04	5.04	4.08	4.41	4.36	4.43	5.95
L2	T2	P1	5.35	4.80	5.86	6.37	7.42	7.66	7.80
		P2	5.01	5.71	5.79	6.37	7.37	7.55	7.68
		P3	4.41	5.61	4.02	4.96	3.83	6.05	7.99

Table A16. Acid detergent lignin of the whole internode in percent of dry matter from which sugars had been subtracted

Loc	Har	Pop	MSC	C3	C1	CO	N	MS	PR
			Hybrid						
			%						
L1	T1	P1	9.12	8.17	9.51	9.53	8.59	8.54	9.97
		P2	10.13	7.40	8.48	8.27	9.71	9.27	10.65
		P3	8.17	7.67	7.40	7.35	8.46	9.51	12.91
L2	T1	P1	7.41	6.19	7.43	8.14	7.95	7.94	9.52
		P2	7.42	6.57	7.08	7.59	7.10	7.87	8.89
		P3	6.84	7.93	7.18	6.74	7.76	8.05	9.23
L2	T2	P1	9.78	7.44	12.08	8.50	10.20	9.75	9.46
		P2	8.21	8.33	8.49	9.35	10.12	10.40	11.20
		P3	7.62	8.59	6.45	8.13	6.28	9.21	10.90

Table A17. Acid detergent lignin of the rind

Loc	Har	Pop	Hybrid MSC	C3	C1	CO	N	MS	PR
			---------------------	------------	------------	%	------------	------------	------------
L1	T1	P1	8.11	7.36	7.67	7.38	8.27	9.02	7.87
		P2	7.61	7.95	7.23	7.18	8.30	7.69	9.32
		P3	7.64	7.13	7.36	6.76	6.93	7.27	9.47
L1	T2	P1	8.12	7.86	7.70	8.73	9.34	9.39	9.41
		P2	7.48	8.07	8.08	7.93	8.53	8.58	10.98
		P3	7.04	6.73	7.42	7.56	7.83	8.58	10.59
L2	T1	P1	7.59	7.23	8.84	7.07	10.03	8.49	9.01
		P2	7.55	7.11	7.18	7.55	8.28	6.29	6.59
		P3	7.45	7.60	5.89	7.33	6.71	9.25	9.41
L2	T2	P1	7.70	7.14	8.17	8.42	8.17	9.92	9.87
		P2	7.91	7.25	8.59	8.66	9.22	9.30	10.27
		P3	7.40	7.60	6.42	7.12	6.22	8.20	11.31

Table A18. Acid detergent lignin of the pith

Loc	Har	Pop	Hybrid MSC	C3	C1	CO	N	MS	PR
			---------------------	------------	------------	%	------------	------------	------------
L1	T1	P1	1.05	1.68	1.64	1.92	1.55	1.50	2.06
		P2	1.05	1.49	1.53	1.46	1.69	1.50	1.54
		P3	1.25	1.62	1.39	1.45	1.08	1.60	2.08
L1	T2	P1	1.06	1.49	1.87	1.96	2.09	2.23	2.84
		P2	0.95	1.60	1.37	2.45	2.08	1.76	2.60
		P3	0.81	3.13	1.43	1.27	1.56	1.83	2.02
L2	T1	P1	0.88	1.18	1.27	1.56	1.53	1.43	1.81
		P2	1.17	1.03	1.40	1.54	0.89	1.34	1.18
		P3	1.00	1.08	1.20	1.27	0.78	1.39	1.28
L2	T2	P1	1.04	1.56	2.01	2.65	2.42	2.78	3.20
		P2	1.04	1.76	1.89	2.49	2.50	2.56	2.40
		P3	1.13	1.38	1.27	1.83	1.34	1.99	2.88

Table A19. *In vitro* dry matter disappearance of the whole internode

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			----------	----------	----------	%	----------	----------	----------
L1	T1	P1	58.74	53.19	51.79	47.64	50.70	52.09	43.15
		P2	58.53	55.77	55.30	51.66	48.95	52.31	45.04
		P3	59.33	55.22	54.22	57.03	58.85	51.95	45.13
L1	T2	P1	59.89	49.67	48.85	46.85	44.67	44.19	33.50
		P2	62.54	47.48	54.79	46.84	47.28	50.50	43.83
		P3	64.80	58.00	55.69	55.64	54.63	48.85	43.78
L2	T1	P1	63.93	60.33	57.04	49.95	53.28	55.68	48.85
		P2	62.64	58.43	60.33	54.79	58.07	53.96	52.59
		P3	63.49	57.94	63.82	60.80	62.03	59.33	53.42
L2	T2	P1	62.35	56.89	51.42	40.91	43.18	41.11	32.13
		P2	62.89	51.21	53.65	46.13	46.36	45.58	44.54
		P3	64.48	56.75	62.05	57.13	66.15	52.87	42.53

Table A20. *In vitro* dry matter disappearance of the rind

Loc	Har	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
			----------	----------	----------	%	----------	----------	----------
L1	T1	P1	45.85	41.89	40.21	38.08	39.77	39.39	34.57
		P2	48.51	44.65	45.83	42.35	36.48	40.31	34.61
		P3	46.35	43.18	44.75	46.07	47.84	40.64	34.77
L1	T2	P1	43.77	38.40	39.22	36.63	33.16	34.00	26.34
		P2	46.30	39.85	43.56	39.38	35.50	37.27	29.71
		P3	50.59	43.54	44.26	45.76	41.29	37.14	34.67
L2	T1	P1	45.88	42.76	43.08	38.35	38.06	40.98	35.61
		P2	45.78	41.71	46.80	43.27	41.86	41.03	38.81
		P3	47.41	42.54	52.03	47.19	50.37	44.10	39.25
L2	T2	P1	46.74	38.53	33.99	29.89	30.84	28.14	23.91
		P2	46.30	34.46	38.47	34.61	32.03	33.53	29.59
		P3	49.23	40.52	47.28	44.38	51.09	38.15	27.62

Table A21. *In vitro* dry matter disappearance of the pith

			Hybrid						
Loc	Har	Pop	MSC	C3	C1	C0	N	MS	PR
			%						
L1	T1	P1	86.73	79.48	79.06	72.35	81.79	82.91	67.97
		P2	87.63	80.40	82.33	75.48	81.08	82.19	71.76
		P3	85.49	79.19	81.63	80.03	86.34	82.29	74.70
L1	T2	P1	84.57	77.17	74.10	71.57	74.80	73.29	56.58
		P2	87.41	78.50	80.45	69.89	76.88	79.16	66.77
		P3	88.22	70.19	80.41	80.80	80.96	78.00	74.17
L2	T1	P1	87.20	84.64	80.35	73.08	81.50	83.11	72.56
		P2	87.44	82.11	81.42	77.77	85.07	82.77	79.45
		P3	87.98	83.12	82.37	81.90	85.82	85.29	82.12
L2	T2	P1	87.94	80.88	71.36	63.06	70.52	70.06	51.89
		P2	87.18	71.93	73.44	68.34	74.06	74.03	71.05
		P3	87.86	81.04	81.39	77.14	83.70	80.08	69.53

Table A22. *In vitro* dry matter disappearance of the stover

		Hybrid						
Loc	Pop	MSC	C3	C1	C0	N	MS	PR
		%						
L1	P1	60.62	52.84	53.28	50.19	49.60	49.73	46.18
	P2	56.18	51.82	53.00	48.10	50.57	49.35	43.87
	P3	55.63	63.76	52.09	54.11	51.27	50.12	46.85
L2	P1		54.45	53.36	51.25	47.12	51.71	47.88
	P2		55.54	56.66	49.89	49.66	51.21	45.03
	P3		57.39	57.34	51.26	56.13	54.25	51.76

Table A23. Grain yield (15.5% moisture)

Loc	Pop	Hybrid C3	C1	C0	N	MS	PR
		quintals ha^{-1}					
L1	P1	45.18	43.34	56.81	62.56	74.26	75.64
	P2	50.54	37.12	39.93	51.05	77.83	53.20
	P3	35.88	30.23	29.74	23.38	54.42	43.93
L2	P1	47.09	47.07	49.07	61.41	70.05	62.87
	P2	42.84	31.41	38.79	45.27	62.59	48.94
	P3	22.42	13.21	26.15	16.29	50.41	41.51

Table A24. Stover dry matter yield

Loc	Pop	Hybrid MSC	C3	C1	C0	N	MS	PR
		tons ha^{-1}						
L1	P1	20.1	7.1	7.8	6.1	8.8	14.6	5.5
	P2	15.9	6.2	6.8	7.2	8.9	11.3	6.1
	P3	17.4	11.9	13.0	6.5	12.5	13.1	7.4
L2	P1		5.9	5.7	6.0	7.5	7.3	5.5
	P2		7.1	8.4	5.5	8.4	7.6	6.5
	P3		8.5	8.6	6.8	9.4	9.8	8.6