

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

YIELDS AND QUALITY COMPONENTS OF MAIZE HYBRIDS FOR SILAGE

A thesis

presented in partial fulfilment of the requirements

for the degree of

Master of Agricultural Science

in

Agronomy

at

Massey University

Ronaldo C. Villaver
1996

ABSTRACT

Seven maize hybrids were evaluated at Frewens Block, Massey University, Palmerston North to determine the effects of hybrid and plant population on yield and yield components, nutritive value, dry matter (DM) partitioning and N%. The range of maturity of the seven hybrids varied from early to full season. The seven hybrids were P3902, Janna, CF1, Furio P3751, P3585 and CG900 each planted at 75,000; 100,000 and 140,000 plants/ha. Plant height, leaf number and yield were measured at 50% silking. Three subsequent samples were taken for estimation of yield, the final yield being at 30-35% whole crop dry matter %. "In Vitro" Digestibility and Kjeldahl N analysis was done by Animal Nutrition Laboratory, Massey University on the grain, leaf, stem and husk components for the 100,000 plants/ha population only.

The effect of hybrid on crop development was closely related to relative maturity. P3902 and Janna, both early maturing hybrids were quickest to reach 50% silking and blacklayer, followed by medium (CF1, P3751, Furio) and late maturing (CG900, P3751) hybrids. Heat unit accumulation of each hybrid followed a similar pattern. Plant height and leaf number differed significantly among hybrids and was related to maturity ranking.

Hybrid CF1 achieved the highest (20,046 kg/ha) whole crop DM yield at final harvest while Janna produced the lowest (15,776 kg/ha) yield. The 75,000 plants/ha plant population yielded significantly less than 100,000 and 140,000 plants/ha. There was no difference between the 100,000 and 140,000 plant populations. This study confirmed the present recommended plant population of 100,000 plants/ha for maize

silage. Dry matter partitioning at final harvest revealed the highest proportion in the grain component followed by the stem, husk and leaf. Total metabolizable energy (ME) content ranged from 11.3 MJME/kg DM to 10.28 MJME/kg DM. The ME content of CF1 was significantly higher than all other hybrids.

Final yield was not correlated with the relative contribution to yield in any of the components or with N % in the crop. However, total metabolisable energy content was correlated with its ME components in the grain, leaf, husk and stem.

There were no significant hybrid differences in whole crop N % which ranged from 1.07 to 1.16%. Nitrogen % of total DM was strongly correlated to N% in the grain and moderately correlated to N % in the stem and in the leaf. NHI was highly correlated with % grain.

CF1 was the best performing hybrid, having highest yield, metabolizable energy and N %. However, among six commercial maize silage hybrids (CF1 is excluded being a non-commercial hybrid at the time of experiment) tested, P3902, Furio, P3585 are the preferred hybrids for early, medium and full season, respectively. The performance of CF1 suggests that there is considerable potential for improving the agronomic characteristics of maize hybrids for silage production in New Zealand through local plant breeding programmes.

ACKNOWLEDGEMENTS

I wish to express my gratitude for the assistance, encouragement, supervision and constructive criticism that I received from my supervisor, Mr. James Millner, Department of Plant Science, Massey University, during the course of my study.

To Mr. Allan Hardacre, Crop and Food Ltd., Palmerston North, I also extend my thanks for his interest and supervision of this project.

I wish also to extend my thanks to the Department of Plant Science Field Technicians, Massey University for their help during the establishment and harvesting of the trial.

To my friends who became involved at various stages of the field and laboratory work I extend my thanks.

My thanks to the New Zealand Government for funding my study under the New Zealand Official Development Assistance Study Award Programme; to the Department of Science and Technology and to the Philippine Government for allowing me to go on study leave.

Finally, to my wife, Pacit and my two children, May Angela and Monica Joy who made considerable sacrifices; to my old mother, who patiently waited on me; my brothers and sisters, my uncle and aunt in-laws and to my sister who passed away while I was in New Zealand, this work is humbly dedicated.

TABLE OF CONTENTS

Title	i
Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Tables	vii
List of Figures	viii
List of Appendices	ix
CHAPTER I Introduction	1
Objectives of the Study	2
CHAPTER II Review of Literature	3
2.1 Introduction	3
2.2 History and Development of Maize	3
2.3 Maize Growth and Development	6
2.4 The Effect of Environment on Maize	12
2.4.1 Temperature	12
2.4.1.1 Prior to Planting	12
2.4.1.2 Planting to Emergence	12
2.4.1.3 Emergence to Tasselling	14
2.4.1.4 Tasselling and Silking	15
2.4.1.5 Maturity	16
2.4.2 Rainfall, Hail and Wind	19
2.5 Management Factors Affecting Maize Production	24
2.5.1 Sowing Date	24
2.5.2 Soil and Fertility	26
2.5.3 Hybrids	34
2.6 Maize Silage	40
2.6.1 Factors Influencing Components and Composition of Maize Grown for Silage	41
2.6.1.1 Plant Maturity at Harvest	41
2.6.1.2 Hybrid Selection	43
2.6.1.3 Plant Population	46
2.7 Nutritive Value of Maize Silage	52
2.7.1 Digestibility and Energy Value	52
2.7.2 Protein Content and Minerals	57
2.7.3 Fibre Content and Fibre Digestibility	58
2.7.4 Maize Silage Moisture Content	61
2.8 Accumulation and Partitioning of Dry Matter in Maize	62
2.8.1. Environmental Influence on DM Partitioning	66
2.8.1.1 Temperature	67
2.8.1.2 Light	70

2.8.1.3 Water and Minerals	71
2.8.1.4 Plant Population Density	73
CHAPTER III Materials and Methods	76
3.1 Experimental Site	76
3.2 Plant Materials	76
3.3 Experimental Design and Layout	78
3.4 History of Experimental Site and Crop Management	78
3.5 Crop Sampling	81
3.6 Analysis of Data	83
CHAPTER IV Results and Discussion	85
4.1 Introduction	85
4.2 Climate	85
4.3 Development of the Maize Crop	87
4.3.1 Vegetative Period	87
4.3.2 Reproductive Period	89
4.3.3 Plant Height	90
4.4.3 Leaf Number	92
4.4 Crop Yields	93
4.4.1 50% Silking	93
4.4.2 Final Total Dry Matter Yields	95
4.4.3 Whole Plant Dry Matter Content at Final Harvest	99
4.5 Dry Matter Partitioning	100
4.5.1 50% Silking	100
4.5.2 Final Harvest	101
4.6 Feed Quality	107
4.6.1 Metabolizable Energy Contents	107
4.6.2 Nitrogen %	109
CHAPTER V Discussion	116
5.1 Climate	116
5.2 Crop Development	116
5.3 Dry Matter Yields	118
5.4 Whole Plant DM Percentage	119
5.5 Dry Matter Partitioning	120
5.6 Forage Quality	123
5.7 Relationships Between Yield, Dry Matter Partitioning and Feed Quality	126
CHAPTER VI Conclusions	129
REFERENCES	131
APPENDIX	169

LIST OF TABLES

Table 2.1	The arrangement of the parental inbred lines for different hybrid types	37
2.2	Typical composition, digestibility and metabolisable energy value of forage maize at the time of harvest	59
3.1	Hybrid characteristic	77
3.2	The 7 x 3 factorial combinations of seven maize hybrids and three plant population levels	79
3.3	Agronomic characteristics, yield and yield components and quality measured in the study	82
4.1	Monthly mean temperature, heat units and rainfall data for the 1994/95 maize growing season at Palmerston North compared with the 30 year mean	86
4.2	The effect of hybrid on time and heat unit requirements from sowing to 50% silking and black layer formation	88
4.3	The effect of plant population on time and heat unit requirements from sowing to 50% silking and black layer formation	88
4.4	The effect of hybrid on plant height and leaf number	91
4.5	The effect of plant population on plant height and leaf number	91
4.6	The effect of hybrid on whole crop yield and percent of yield present as stem, leaf and husk at 50% silking	94
4.7	The effect of plant population on whole crop yield and percent of yield present as stem, leaf and husk at 50% silking	94
4.8	The effect of hybrid on whole crop DM yield; crop DM%; percent yield present as stem, leaf, husk and grain, at final harvest	96
4.9	The effect of plant population on whole crop DM yield; crop DM%; percent yield present as stem, leaf, husk and grain, at final harvest	96
4.10	The variation in metabolizable energy content of among hybrids planted at 100,000 plants per hectare	108
4.11	The variation in overall N% and its corresponding percentage in plant components, NHI and N yield among maize hybrids planted at 100,000 plants per hectare	110
4.12	Simple correlation coefficients for final yield, % yield in grain, stem, leaf and husk, total metabolisable energy and metabolisable energy of different plant fractions	113
4.13	Simple correlation coefficients for final yield, nitrogen %, yield components, total nitrogen %, nitrogen harvest index, nitrogen yield, grain yield and % grain	115

LIST OF FIGURES

Figure	4.1	The effect of hybrid on DM accumulation between 50% silking and final harvest	97
	4.2	The effect of plant population on DM accumulation between 50% silking and final harvest	98
	4.3	Dry matter partitioning in maize hybrids at final harvest	102
	4.4	The effect of hybrid on percent stem between 50% silking and final harvest	104
	4.5	The effect of hybrid on percent leaf between 50% silking and final harvest	105

LIST OF APPENDICES

Appendix	1	Daily temperature data with the corresponding heat unit for the 1994/95 maize growing season at Palmerston North	169
	2	Rainfall data for the 1994/95 maize growing season at Palmerston North	175

CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is, after wheat and rice, one of the most widely grown staple starchy food crops. It can be grown in warm temperate, continental and tropical climatic zones.

In New Zealand, there are on average approximately 19,000 hectares sown to maize annually yielding 180,000 tonnes of grains. About 70% of grain produced in New Zealand is used by the animal feed industry, primarily for pigs and poultry production. The remaining 30% is milled to produce a range of grits and flours. (Hardacre et. al. 1991).

In addition to the grain which represents from 30 to 50% of the total crop dry matter, other plant components such as stalk, leaves, husk and cob can be utilised as a feed source for ruminant animals (Hunt et. al. 1989). These nongrain plant parts may be harvested with the grain, as in maize or corn silage, or separately as crop residues.

Maize producers face many management decisions for each crop they grow. Among these hybrid selection, planting date, plant population and fertilization are the most important. Although the effects of varying any one of the above mentioned factors are fairly well known, the combined interacting effects of changing these factors have to be studied in view of the development of commercial maize hybrids. Because, the final yield is influenced by the above mentioned interactions, it is very important that

these factors be considered all together. However, in maize grown for silage, consideration of feed quality is also very important in establishing its contribution towards meeting an animal's needs.

In most countries maize hybrids for silage are selected on the basis of grain yield, reasoning being that the best grain genotype produced a high yielding high quality silage (Pollmer, 1980; Hunter, 1986). However, several researchers have found no convincing evidence to support this widely held belief (Gunn, 1978; Hunter, 1978). Recently, Roth and Undersander (1995) mentioned that differences exist among commercial maize hybrids in digestibility, fibre and protein content. They added that within a group of commercial hybrids, there will be a few with superior quality, most with average quality and a few with significantly less than average quality. These differences in quality can translate into differences in animal performance. This study was conducted to independently evaluate agronomic characters and feed quality on the recent commercial maize silage hybrids recommended for planting in the Manawatu region.

OBJECTIVES OF THE STUDY:

To determine the effect of hybrid and plant population on:

- 1) the yield and yield components of maize silage;
- 2) the nutritive value of maize silage;
- 3) the partitioning of dry matter and protein in maize silage after silking.

CHAPTER II

REVIEW OF LITERATURE

2.1 INTRODUCTION

Maize is a major forage species. As a forage, it is used primarily in the production of whole-plant maize silage (Hunter, 1986). High dry matter yield, high feeding quality for ruminants and sufficiently high dry matter content to ensure proper fermentation and high intake by livestock are regarded as the primary objectives in silage maize production (Hunter, 1986; 1978). In New Zealand, seven to eight thousand hectares of forage maize are grown each year (Douglas, 1980) with production increased recently in the South Island, particularly in Canterbury region (Wilson et. al. (1994). The crop has been used for many years in the north island as greenfed for cattle and sheep or for silage and has been suggested as a summer crop for forage and silage in Canterbury and Otago.

2.2 HISTORY AND DEVELOPMENT OF MAIZE

Maize is one of the leading cereal grains produced, consumed and traded in the world today. The cultivation of maize is thought to have posed a mystery because no wild ancestor from which it could have originated has ever been found. However, this mystery of maize origin was cleared in 1954 when Barghoorn et. al. (1954) reported identification of maize pollen in a drill core taken 70 meters under Mexico City from strata established as being 80,000 years old.

One United Nations study estimates that 90% of the world's food supplies come from the land. According to this analysis, cereal grains (wheat, maize, rice, barley, sorghum, etc) provide an incredible 68% of world food supplies. The remaining percentage comes from other foods such as tubers, fruits and vegetables, which account for 22%, and 10% from the world's oceans and lakes, in the form of fish and other aquatic life (Oleson, 1994).

Cereal grains are commonly designated as either food (wheat and rice) or feed/coarse grains (maize, barley, sorghum, etc.), based on their primary end-use. The world production of cereal grains over the past five years (1986 to 1990) has averaged 1.661 billion tonnes. Maize was the second largest grain produced, after wheat, averaging 451 million metric tonnes. Wheat and rice production were 533 million metric tons and 331 million metric tons annually, respectively.

Maize being a C4 plant is considered to be well adapted to the warmer regions of New Zealand. The North Island accounts for virtually all of the total New Zealand maize production. About 70% of grain maize grown in New Zealand is used in the feed industry and the rest is utilized to produce starches used in industry and as a human food - glucose, cornflour and alcohol (Newton, 1984).

The introduction of maize in New Zealand occurred in 1772 and was known to be grown by the early settlers- the Maoris, who at first ate the maize grain raw. In subsequent years, Maoris adopted the European methods of cooking and started to boil, roast, or even pop the grain. They also developed the methods of soaking the grain or

rotting the unhusked cobs for 2 - 3 minutes before scraping off the soft, slimy grains which were made into a number of dishes (Bansal and Eagles, 1985).

From 1966 onward, maize production in New Zealand increased dramatically. It peaked at 29,000 hectares in 1977, after which production decline as farmers diversified. Presently, there are approximately 19,000 hectares sown to maize (Hardacre et. al., 1991).

Currently, all maize cultivars grown commercially in New Zealand are hybrids, although, open pollinated lines are occasionally grown. These hybrids have been selected to be very high yielding and resistant to disease and lodging. It is worthwhile mentioning that the first maize hybrids were introduced in 1940. It was not until the expansion of the maize industry in the 1960's that high yielding hybrids were introduced to New Zealand by companies which negotiated franchises with seed companies in the United States. These commercial companies hold stocks of inbred lines used to produce F1 hybrids which they sell to maize growers thereby controlling the production of maize hybrid seeds (Connel, 1985).

Maize has three major end uses: as food, as raw material for industry and as fodder for animals.

As food, the whole grain either mature or immature is used or processed by dry milling techniques to give a large number of intermediary products such as maize grits of different particle size, maize flour and flaking grits. These materials inturn have a

great number of applications in a large variety of foods (Chappel, 1985; FAO, 1992).

Dry milling of maize produced germ and seedcoat as byproducts. The former is used as a source of edible oil of high quality. The seedcoat or pericarp is used mainly as a feed and as source of dietary fibre. Wet milling is a process applicable mainly in the industrial use of maize. It yields maize starch and byproducts such as maize gluten which is used as food ingredient (FAO, 1992).

Maize as a fodder crop is popular mainly in developed countries, including New Zealand. Buxton (1975) suggested that the reasons for the increase in area of maize as a fodder crop in New Zealand is due to:

- (1) frequent occurrence of dry summers, causing farm production to fall, especially in dairy production;
- (2) maize can yield large quantities of green fodder per hectare relative to most alternative summer fodder crops and summer production; and
- (3) maize silage yields can equal, and often exceed, annual pasture dry matter per hectare.

2.3 MAIZE GROWTH AND DEVELOPMENT

Hershey and Paddick as cited by Shaw (1955) divided the corn plant development into five different stages, each with each own relation to final yield. Shaw and Loomis (1950) also divided the development of corn into five stages while Fischer and Palmer (1984) reported the widely recognized cardinal phenological points of maize,

delineating the vegetative, reproductive and grain-filling periods. Hanway (1966) developed a 10-stage, plant development system ranging from 0 when the plant tip emerges from the soil to 10 when the plant is physiologically mature. These 10-stages will be described in this review.

All normal maize plants, wherever they are grown will follow the same general pattern of development, but the specific times between stages and number of leaves developed may vary between different hybrids, different seasons, different dates of planting and different locations. Examples of these variations:

- 1) an early maturing hybrid may develop fewer leaves or progress through the different stages at a faster rate. A late-maturing hybrid may develop more leaves or progress more slowly;
- 2) the rate of development for any hybrid is directly related to temperature, so the length of time between the different stages will vary as the temperature varies, both between and within growing seasons;
- 3) increased daylength early in the development of the plant results in more leaves per plant and lengthens time between plant emergence and flowering or silking;
- 4) deficiencies of nutrients or moisture may result in lengthening the time between different stages before silking; and
- 5) the number of kernels which develop, the final size of the kernels, and the rate of weight increase of the kernels influences the length of the period from silking to maturity. This will vary between different hybrids and different environmental conditions.

The growth stages of maize and the corresponding identifying characteristics developed by Hanway (1966) is described as follows:

Stage 0 - Plant Emergence - when maize is planted at the usual time, late October to early November for most North Island crops in New Zealand, commonly occurs in about 8 to 15 days after planting depending on the prevailing soil temperature and moisture conditions. The embryo in the seed has five leaves and the primary roots have been initiated. The period from planting to emergence is characterized by a dependence on seed-stored food (Berger, 1962).

Stage 1 - Four leaves fully emerged, 2 weeks after plant emergence - this is approximately the stage of tassel initiation and the end of the period of differentiation of leaf initials (Poethig, 1994). Thus, the number of leaves that will develop on the maize plant has been determined by about this time. The genetic characteristics of the plant, day length and various environmental conditions prior to this stage will have determined the number of leaves that will develop on the plants. The growing point of the stem is at or slightly below the soil surface.

Stage 2 - Eight leaf fully emerged, 4 weeks after plant emergence - this stage is in the middle of the period of rapid leaf growth. The stem has just started rapid elongation. The growing point at the tip of the stem is 15.2 to 20.3 cm above the soil surface. The rate of nutrient uptake becomes rapid at this stage with any nutrient deficiencies seriously restricting leaf growth. Nitrogen fertilizer may be effectively sidedressed up to this stage if the fertilizer is placed in moist soil and if serious injury

to the root system, through root pruning is avoided. N and P uptake continue at this rapid rate until near maturity. Uptake of K, Ca and Mg continues at this rapid rate until silking stage (stage 5) but relatively little is taken up after that time, and some K may be lost from the plant later in the season.

Stage 3 - Twelfth leaf fully emerged, 6 weeks after plant emergence - at this stage, maximum dry matter accumulation occurs. Under favourable conditions, dry matter accumulation in the above ground parts of the plant proceeds as essentially a linear function of time from this stage to near maturity (stage 9). Leaves develop a green color and increase in weight after they emerge from the whorl and are exposed to light, but they do not increase in length or width (area) after they are fully emerged. This stage is near the middle of the period of rapid growth and elongation of the stem. The tassel is well developed but is still enclosed within the whorl of leaves (Cheng and Pareddy, 1994). Root growth is rapid. This is also a critical period in determining the size of the uppermost ear (or ears).

Stage 4 - Sixteenth leaf fully emerged, 8 weeks after plant emergence - at the this stage, the husks of the uppermost ear, which usually occurs at the node between the 12th to 14th leaf, are apparent and are beginning rapid growth (Cheng and Pareddy, 1994). The ear within the husks will be about 2.54 cm long but is beginning to grow and develop rapidly. Silks from the base of the ears also elongate rapidly.

Stage 5 - Silks emerging, pollen shedding; 66 days after emergence - this stage is easily identifiable by the emergence of silks and the shedding of pollen. The tassel,

the stem and the leaves are all fully grown. The tassel was fully emerged 2 to 3 days prior to the appearance of the silks (Kiesselbach, 1949). The plants have attained their full height. Vegetative growth has ceased and all future growth occurs in the ear. The cob and ear shank have nearly completed growth. The cob and silks are growing rapidly. Ovules are enlarging. The silks from the ovules near the tip of the ear have not yet emerged and will continue to elongate until they are fertilized by the pollen, thus the number of ovules that will be fertilized will be determined at this stage.

Stage 6 - Blister stage, 12 Days After Silking - the cob and ear shank are approaching full size. The kernels are in the "blister stage", having enlarged considerably especially the endosperm, but the kernels contain very little dry matter (Larson and Hanway, 1977). The coleoptile, the 1st leaf and the radicle have just been initiated in the embryo. Vascular development in the radicle is initiated at about this time. Starch has just begun to accumulate in the endosperm. This is the beginning of the period of rapid dry matter accumulation in the kernels, which will continue at this rapid, essentially constant, daily rate until stage 9. Loss of N and P from other plant parts to the developing grain begins about this time and continues until physiological maturity.

Stage 7 - Dough stage, 24 Days After Silking - between stages 6 and 7, the growth of the entire kernels is rapid but the rate of growth of the embryo is slow in comparison with the rapid growth of the endosperm. In the embryo, the main plumule-radicle axis is fully differentiated by stage 7 and the 4th leaf is usually present. Stage 7 represents the end of cell division in the epidermal layer of the endosperm and the

beginning of a rapid increase in size of the embryonic plant. This stage is describe as the period of rapid increase in grain weight and the development of the young plant in the embryo of each seed.

Stage 8 - Beginning dent stage. A few kernels are showing dents, 36 days after silking - the growth of the embryo is very rapid, and the radicle and embryonic leaves become fully differentiated. Seminal roots are initiated at 30 to 40 days after silking. Enlargement of the endosperm after stage is chiefly due to an increase in cell size. About 25% of the plants at stage 8 have some kernels with "dents".

Stage 9 - All kernels fully dented, 48 days after silking - by this stage, the rate of dry matter accumulation by the plant has begun to decline. All the kernels are fully "dented". Prior to stage 9, the embryo is morphologically mature, but there may be a further slight increase in size throughout the embryo. According to Sass as cited by Duncan (1975) there are usually 5 seedling leaves when the kernel is mature.

Stage 10 - Physiological maturity, 60 days after silking - in here, the plants are physiologically mature, meaning, dry matter accumulation has ceased. The husks and some of the leaves are senescent. However, the ear (cob and grain) will continue to lose moisture after this time. The rate of water loss will depend upon climatic conditions, the moisture content of the ear at this stage, which varies between different hybrids, and other factors. Harvesting for silage at this stage is recommended.

2.4 THE EFFECT OF ENVIRONMENT ON MAIZE

2.4.1 Temperature

Maize, because of its many widely divergent types, is grown over a wide range of climatic conditions. This review will consider the influence of climate, notably rainfall and temperature on the development and production of maize.

2.4.1.1 Prior to Planting

The influence of climate on the maize plant begins before planting. Conditions before planting are especially important in determining soil moisture reserves and the time of seedbed preparation. Spring weather may help replenish soil moisture reserves due to the occurrence of rains. However, excessive rainfall during this season will cause waterlogging affecting early growth of the developing maize seedlings. Wilson et. al. (1991) and Hardacre et. al. (1991) pointed out the climatic risk, due to low soil temperature and the risk of damaging late spring frosts of sowing in early October in New Zealand.

2.4.1.2. Planting to Emergence

The period from planting to emergence is characterized by a dependence on soil temperature, soil moisture and seed-stored food. Before germination, the seed imbibes water and swells. Water must be available for imbibition and subsequent seedling

growth. A suitable temperature must be present for both germination and later growth to take place. The time from planting to emergence varies widely with environmental variations. McCormick (1974) in his sowing date study on maize under New Zealand conditions reported that germination took longer with early sowing as soil and air temperature were lower.

Low temperature at seeding limit corn production in cool early season environments (Hope et. al. 1992). It reduces emergence rate (Dubetz et. al. 1962; Mock and McNeil 1979) and increases susceptibility to seed and seedling diseases which reduce seedling vigour resulting in poor stand establishment (Schulz and Bateman 1968).

Usually, gradual soil warming occurs after sowing, but if temperatures remain cool, emergence rates can be reduced significantly (Miedema 1982; Andrews 1987). When soil moisture is near field capacity, seedbed temperature becomes the most critical environmental factor affecting corn emergence (Scheider and Gupta 1985; Al-Darby and Lowery 1987).

Soil temperature strongly affects the rate of germination and early corn growth at least until the growing point emerges above the soil (Coelho and Dale 1980). Soil temperatures are therefore recommended to characterize the thermal regime from planting to emergence (Dwyer et. al. 1990). Investigators developed models to estimate soil temperature from measured air temperature (Hasfurther and Burman 1974; Toy et. al. 1978; Meikle and Treadway, 1981; Gupta et. al. 1983).

The growing degree day (GDD) is commonly used to characterize the thermal environment during crop development (Kiniry and Keener 1982). The minimum threshold temperature for maize germination and emergence is at 10°C (Scheider and Gupta 1985; Jones et. al. 1986, Al-Darby and Lowery 1987). Segeta (1960) found that at 10°C , seedlings often died before emergence. Alessi and Power (1971) reported a high correlation ($r=0.79$) between percent emergence and cumulative-degree days above 10°C .

2.4.1.3. Emergence To Tasselling (Vegetative Growth Period)

An important change takes place shortly after emergence when the plant changes from one of dependence on stored food to one of self-sufficiency. The maize plant in its early life needs a limited quantity of moisture for the small growth that takes place. As it continues to grow, roots will penetrate the soil to provide for increased moisture requirements. (Shaw, 1955). In the field, the primary root and the seminal or seed roots will be supplanted by others to form the permanent root system which will be capable of supplying all of the nutrition for the fully developed plant (Duncan 1975).

Temperature affects the rate and duration of crop development from sowing to grain maturity and together with daylength, is one of the major environmental factors influencing the adaptation of maize cultivar to particular environment (Brooking and McPherson 1989). Maize is grown as a grain crop over a wide range of temperature environments between latitudes 40 degree S and 55 degree N (Chang 1981; Shaw, 1988). Its responses to the wide range of temperatures in its developmental processes

between sowing and anthesis have been studied by many researchers (Blacklow 1972; Tollenaar et. al. 1979; Warrington and Kanemasu 1983a,b,c).

The sensitivity of a crop species to chilling frequently restricts the environments in which it can be cultivated. Maize grown in temperate regions is often subjected to chilling conditions before and after emergence which can lead to disruption of development (Cutworth and Shaykewich 1990; Hope et. al. 1992). The introduction of maize lines with high potential for emergence under chilling conditions in temperate regions would aid in stand establishment and in potentially stabilizing and optimizing grain yields (Hodges et. al. 1994).

Under New Zealand conditions, the average annual yield of maize grain in the Waikato has ranged from 6.5 to 8.2 tons/ha over the past 10 years (McCormick 1980). The yield variation can be accounted for predominantly by seasonal differences in temperature during the first month of growth- November, with low temperatures reducing yield (McCormick 1979). Hybrid cultivars more tolerant of cool temperatures during early growth could reduce annual yield variation and increase average yield.

2.4.1.4. Tasselling and Silking

The time of tasselling is determine by the temperature previous to this period. Maize being a warm-weather crop requires warm temperatures from the time of planting until anthesis (tasselling and silking), and once it is above the ground will tolerate only very brief and light frosts.

During the period of vegetative growth , and particularly during the three weeks preceding and following anthesis, the period when the growth rate is very rapid and at its peak, temperature should be moderately high both day and night and moisture and nutrient levels should also be high.

In temperate areas and specifically in the cornbelt of the United States, La Plata cornbelt in Argentina, the Garonne Basin of France, Italy's Po Valley, and the Hungarian and Walachian basins, the six regions which produce roughly three-fourths of the world's maize and which are considered to have almost ideal climatic and soil conditions, fairly specific physical requirements are recognized. According to van Royen (1954), summer temperatures should average about 23.9°C, with warm nights-average night temperatures of 14.4°C; rainfall should be fairly abundant, from 460 to 600 mm during the growing period, and during the summer months, it should be of the thundershower type, with periods of clear, warm weather in between.

2.4.1.5. Maturity

Early researchers based their estimate of maize maturity on the internal measurements such as moisture content and external appearances of the ear or the plant (Shaw and Thom, 1951; Hallauer and Russel, 1962). Shaw and Thom (1951) reported that the use of grain moisture content as an estimate of maturity lacked generality because of the wide range (28% to 48%) of grain moisture at maturity. On the other hand, Hallauer and Russel (1962) mentioned external characteristics such as the relative denting, or glazing of the kernels, or the relative browning of the husks or plants as the

basis for determining maize maturity. Duncan (1966) reported that the term, physiological maturity, which denotes the time of maximum dry matter accumulation in the grain, is generally accepted by maize researchers as basis for determining maize maturity. Daynard and Duncan (1969) presented evidence that blacklayer formation in the placental region of maize kernels represents a precise indicator of the date of attainment of maximum grain dry weight. This was confirmed in the subsequent work of Daynard (1972) where he concluded that blacklayer development served as a useful end-point for characterizing maize hybrids as to their relative maturity and their adaptabilities to various localities.

In as much as the interval from silking to maturity appeared to be relatively constant, the maturity of maize has frequently been measured by recording the number of days of heat units from planting to silking (Hallauer and Russel, 1962; McCormick, 1983). A cultivar, regardless of the date of planting needs the same number of "heat units" (day-degrees) to reach a given stage of maturity. A farmer using the basic weather information can calculate the number of heat units available and can work out how long the crop will need to mature. This calculation can be made using the equation:

$$\text{Daily heat units} = \frac{(T_{\text{max}} - 10) + (T_{\text{min}} - 10)}{2}$$

2

where:

T_{max} = maximum temperature (°C)

T_{min} = minimum temperature (°C)

if T_{min} is less than 10°C, take $(T_{\text{min}} - 10) = 0$

These daily heat units are summed until the total required by a cultivar to reach mid-silk is obtained. McCormick (1983) reported that under New Zealand environment, sixty five (65) days is added to the number of days from planting to mid-silk to give the date of maturity. Early works of Hallauer and Russel (1962) and Hanway and Russel (1969) under Iowa conditions required a range of 43 to 60 days and 50 to 60 days, respectively after silking to produce the final grain yield. Shaw and Thom (1951) concluded in their investigation under similar environments that the average interval from silking to maturity was approximately 51 days and very constant, and because of its constancy, it could be used to forecast maturity.

In a related study, Daynard (1972) observed that a delay in planting date resulted in an increase in the number of accumulated heat units required from planting to mid-silking, and a decrease in number of heat units from mid-silking to maturity (blacklayer formation). McCormick (1983) mentioned that maize hybrid W304 planted in five different sowing dates under New Zealand conditions required similar number of heat units to reach mid-silking stage.

Gilmore and Rogers (1958) compared 15 thermal unit methods for predicting silking in maize. The method that had the least coefficient of variability (CV) involved correction for temperatures below 10°C and above 30°C and they referred to this as effective degree days (EDD). Whereas calendar days varied with planting dates, EDD remained more or less constant. Gunn and Christensen (1965) evaluated five heat unit methods in maize and found that the lowest CV was associated with the method that made adjustments for temperatures below 10°C and above 28.8°C. Derieux and

Bonhomme (1982) working on the heat unit requirements for maize hybrids in Europe observed that during the entire period from sowing to silking, temperature played a very important role and the CV they obtained in their maize trials is about 7-8%. Under hot tropical rainforest conditions, Abasi et. al. (1985) found that the best heat unit method for predicting silking dates utilized an optimum temperature of 30°C and a base temperature of 10°C and corrects for the effects of temperatures above 30°C on growth.

2.4.2 Rainfall, Hail and Wind

The amount of water a crop needs is mainly determined by its stage of development and by the weather. For maize, the water requirements are low during the period of crop establishment and early vegetative growth, but then rise steadily as rates of leaf expansion and stem elongation increase (Carr and Hough, 1978). For example, in Northern Europe, the water requirements of maize are at their maximum during July and August when the rates of vegetative development and of potential evaporation reach their peak, but decline during September when leaf senescence begins and rates of evaporation decline. Berry (1977) reported that maize requires approximately 1100 to 1500mm of rainfall per hectare during the entire growing season in New Zealand. The requirements varied according to soil water retention capacity. On a monthly basis, Newton (1984) mentioned an ideal rainfall during the November-March period of 100 mm per month. In the United States, Berger (1962) reported that the optimum growth of maize requires 460-600 millimetres of rainfall.

Maize is potentially a more reliable summer producer than pasture and could become a useful forage source in districts where water supplies are short and periodic summer droughts occur. Maize uses much less water during the growing season than perennial forages such as lucerne or pasture. The ability of the crop to conserve water during its establishment has been shown by both direct measurement (Kerr et. al. 1973) and simulation studies (Kerr and Clothier, 1975). Estimates for the seasonal maximum evapotranspiration for the period November 1974-February 1975 inclusive at Palmerston North were 525 mm. Perennial forages such as lucerne or pasture require a similar quantity of water if they are to maintain satisfactory growth. Over the same period the evapotranspiration predicted for an irrigated maize crop was 291 mm, approximately 60% of the pasture requirement.

Evapotranspiration (ET) does not vary greatly from year to year whereas rainfall can be very erratic. The lower seasonal water requirements of maize relative to pasture mean that its production is less affected by drought. This potential will be maximised on deep silt loam soils with a good water holding capacity.

In situations where rainfall is slightly limiting additional irrigation can be very beneficial. Linear relationships have been established between yield and water use for several different environments. An estimate of 780 kg/ha grain/cm ET has been made by Kerr and Clothier (1975), compared with 240kg/ha grain/cm ET for maize grown in California (Stewart and Hagan, 1973) and 445 kg/ha grain/cm ET for maize grown in Israel (Hillel and Guron, (1973). These differences maybe due to various management techniques, differences in maximum evapotranspiration, or to differences in yield

interaction with environmental factors other than water (Kerr, 1975).

Research efforts in modelling and improving crop yield have focused extensively on the supply and demand of water in the soil-plant-atmosphere continuum. Soil water deficits affect practically every aspect of plant growth and development (Berard and Thurtell, 1991). In maize, grain yield is highly dependent on water availability during the period spanning tasselling-to-silking and for approximately two weeks after silking (Denmead and Shaw, 1960; Shaw, 1974). Schussler and Westgate (1991) suggested that reduced photosynthetic activity caused by water deficits is the reason of poor seed set in plants growing in pots. Simultaneously Boyle et. al. (1991) demonstrated that sucrose infused in the stems of water stressed maize plants at flowering, also grown in pots, greatly reduced reproductive failure. These studies indicated that reproductive success in maize subjected to water stress at anthesis is strongly related to growth.

Water deficits at flowering decrease grain yield in maize even if pollination occurs (Schussler and Westgate, 1991; Westgate and Boyer, 1986b; Zinselmeier et. al. 1991). Although silk and ovary water potential decrease in water-deficient plants (Westgate and Boyer, 1986a; Bassetti and Westgate, 1993; and Schussler and Westgate, 1991), fertilization still can occur after silks are pollinated at water potential as low as -1.0 MPa (Westgate and Boyer, 1986b; Bassetti and Westgate, 1993). Kernel loss in pollinated plants occurs because zygotes abort soon after fertilization (Westgate and Boyer, 1986b).

In New Zealand, recurrent and variable drought is one of the chief causes of season-to-season variation in grain yield (Jamieson et. al., 1995). Much of the cereal growing area is prone to summer drought. Most of New Zealand's wheat and barley is grown in Canterbury, and there is an expanding area of maize. This area has summer potential evapotranspiration approximately twice its mean rainfall. The seasonal shortfall in rainfall is exacerbated by its large variability, both between and within years. Further, Kerr (1982) reported that water stress can occur at anytime when transpiration exceeds water absorption by the roots even though adequate water is available in the soil.

On the other hand, excess water can have a significant effect on crop productivity. Kerr (1982) estimated that in 1973 alone, an estimated 2 Million hectares in New Zealand are either permanently or seasonally wet which representing 40% of the 5 Million hectares of cultivable land. Schwab et. al. (1966) in their study on the effects of flooding on the survival and growth of maize found that 7.6 cm application of water to undrained soil when corn was less than 20.3 cm tall and another 7.6 cm application when it was 24 inches tall drastically reduced yields. Lal and Taylor (1969, 1970) concluded that intermittent flooding early in the growing season reduced yield of corn more than did constant water tables of 15 and 30 cm. The uptake of N and Zn by corn plants was significantly reduced by high water tables and intermittent flooding. They concluded that reduced nutrient uptake was partially due to the limited root system, prevalence of reducing conditions in soil, a deficiency of soil oxygen and possible CO₂ toxicity. Chaudhary et. al. (1975) found that grain yields were reduced significantly by submergence exceeding one day. Submergence during early growth was more harmful than during late growth. Prolonged soil submergence significantly reduced N,

P and K concentration in the grain.

Hail is an important weather phenomenon in that it can cause serious reduction in yield. The term hail, refers to the solid precipitation in the form of balls or pieces of ice (hailstones) with diameter, ranging from 5 to 50 mm or more (Lewis, 1991). A day of hail is defined as one when pieces of ice, 5 mm or more in diameter, are observed to fall at anytime between midnight and midnight. Because of the difficulty in estimating yield losses as a result of hail damage in the field, where no control treatment exists, studies have been conducted to simulate defoliation caused by hail damage (Dwyer et. al. 1994). In defoliation studies, grain yield reductions were influenced by the extent of defoliation and crop stage (Camery and Weber, 1953). Complete defoliation at tasselling resulted in almost total yield loss (Camery and Weber, 1953) but the later defoliation occurred during grain filling, the smaller was the yield reduction (Trappeniers et. al. 1992).

Wind lodging of maize is most likely to occur when plants are in the mid-vegetative stages, and have not yet developed adequate brace roots to provide firm anchorage during severe wind and rain storms (Ritchie and Hanway, 1982). When soils are saturated by heavy rainfall and the rainfall is accompanied or followed by high wind speeds, wind-induced corn root lodging may occur (Carter and Hendelson, 1988). In severe situations, entire maize stands may be blown nearly horizontal away from the direction of wind. After a few days, the plants usually move upward such that the upper stalk is vertical, but curvature occurs in the lower stalk area.

Wind is obviously an important environmental stress factor for plant production particularly in New Zealand (Kerr, 1982). It can significantly modify the environment in which the plant is growing as well as causing physical damage to the plant, altering the plant's water balance and plant temperature.

2.5. MANAGEMENT FACTORS AFFECTING MAIZE PRODUCTION

2.5.1. Sowing Date

In tropical and subtropical maize growing regions, the time and the distribution of rainfall normally determine maize-sowing time, whereas in the temperate zones, this largely depends on temperature. Maize requires a relatively high temperature for germination (Bunting 1978) and is extensively sensitive to frost. Sowing time in many maize production areas is therefore determined by soil temperature and by the incidence of late frost, the latter naturally varying in different growing regions (Schrimpf, 1966). Field studies by Bunting (1978) of the effect of sowing date suggest that little advantage in time of emergence is gained by sowing before the mean soil temperature at seeding depth (5 cm) exceeds 10°C. Delayed sowing will reduce grain yield but may increase vegetative growth. The increase in vegetative growth with delay in sowing is usually attributed to the effect of day length (Becker, 1955), but higher soil temperatures during early stages of development are probably as important (Coligado and Brown, 1975; Hunter et al. 1974). Although yield of forage is much less affected than grain production by variation in sowing date, crops grown for conservation should be sown early to ensure percent dry matter at harvest is as high as possible. Delay in sowing

will also adversely affect the relative contribution of grain to stover (stem and leaf) in the crop.

Several planting date studies in the United States have shown the value of early planting for increasing yields (Alessi and Power, 1975; Cummins, 1975; Larson and Hanway, 1977). In northern areas of the United States, the optimal dates have been in early May (Alessi and Power, 1975; Rossman and Cook, 1966). Various studies have indicated that significant yield reductions occur with late planting, regardless of the maturity of the hybrid. These reductions in early and late hybrids generally have been similar on a percentage basis, but on actual yield basis- the later hybrids have suffered the largest losses (Alessi and Power, 1975; Cummins, 1975). This has led some researchers to suggest that early hybrids can be planted relatively late and still yield satisfactorily but that later hybrids cannot (Alessi and Power, 1975). In the work of Knapp and Shaw Reid (1981) in New York, grain and silage data indicated that maize planting before 15 May maximized yields. Each day planting was delayed after May 15 decreased grain yields by 28 to 253 kg/ha., depending on the hybrid. Yields of the longer season hybrids tended to decrease more rapidly than early maturity hybrids, however, the long season hybrids had higher yields overall.

In a maize sowing date study in New Zealand, McCormick (1971) reported that when sowings were made from mid October to mid December, it was observed that, with early sown maize, plants were often shorter, formed a less dense canopy and produced a higher grain to total plant dry matter ratio. Such observations agreed in principle with the findings of Pendleton and Egli (1969) who showed a leaf area per

plant to be less for early sown maize and the grain per unit leaf area to be higher. An explanation for the higher production of grain per unit leaf area with early sowing is that grain formation occurs closer to midsummer when days are longer and the angle of incidence of the sun is greater so that more radiant energy is available for photosynthesis. In a second study McCormick (1974) found that where maize (PX610) was sown at approximately 2 week intervals from midSeptember to mid November, development to maturity and harvest took up to 24 days longer with early sowing. This was because soil and air temperatures were lower with early sowing. Germination, vegetative development and grain drying took longer and plants sown early were characteristically short, had thicker stems and a smaller leaf area. Menalda and Kerr (1973) found that sowing date and hybrid relative maturity have a significant effect on maize development and will largely determine the time at which the crop is ready for green-chop or ensiling. Early maturing KC3 sown on 26 October was the only hybrid ready for ensiling in late February. All hybrids sown on 26 October and the early and medium maturity hybrids on 8 November were ready for ensiling on 20 March. All treatments except the late sown (29 November) PX610 were suitable for ensiling by mid April.

2.5.2 Soil and Fertility

Maize is an excellent example of crop adaptability to soil conditions being grown on a wide variety of soils (Berger, 1962) except cold, moist clay or very light sandy soils (Schrimpf, 1966). Successful maize cultivation is more frequently and more easily achieved on soils which are of medium texture (Bland, 1971). With soils of light texture

there is greater risk of drought.

Berger (1962) reported that maize performs best on well-drained aerated, deep, warm loams and silt loams containing an abundance of organic matter and well supplied with available nutrients. In Europe, highest maize yield occur on deep medium loam soils of near neutral pH (Bunting, 1978).

Maize, being highly responsive to soil fertility prefers a rich well drained soil with a pH between 5.5 - 8.0 ((Newton, 1984; Hardacre et. al. 1991). If lime is required, it should be applied at least 6 months prior to sowing to allow time for the soil pH to increase. Fertile clay or sandy loams, good volcanic soils and peats or well drained swamplands are suitable. Root growth is restricted on tight clays or shallow soils and maize should not be sown on these areas.

Good drainage is essential. Wet soils prevents early cultivation and causes harvest machinery to bog in late autumn or early winter. It also induces root and stalk roots. Water is required throughout the growing season (Newton, 1984)

An adequate supply of plant nutrients is essential for normal plant growth. Supplies of plant nutrients are provided by rain, soil reserves, plant residues, chemical fertilizers and manures (Pain, 1978).

Nutrients required by plants are often grouped in three categories: Major nutrients (N, P and K); secondary nutrients (Ca, Mg, Na, S) and micronutrients or trace elements which include iron, boron, zinc, copper, manganese, molybdenum and chlorine. The trace elements are essential for normal plant growth but requirement is very small and maybe toxic in excessive quantities.

In deciding how much fertilizer to apply, Steele (1985) reported that the following information is required to estimate the amount and type of fertilizer to be applied on the maize plant:

- (i) the total nutrient requirements of the crop
- (ii) the time when the crop requires particular nutrient
- (iii) the amount of each nutrient removed in crop products
- (iv) the amount of each nutrient provided by the soil
- (v) the proportion of any added fertilizer that will be taken up by the crop.

The nutrient requirement of maize is dependent on the level of attainable yield or yield goal, soil type, climatic conditions, previous crop, field history of manure or organic waste application and other crop management (Steele, 1985; Fageria, 1992; Eckert and Martin, 1994). Maize production regions differ substantially in their level of yield because of variations in soil and climate from field to field and from year to year (Schrimpf, 1966; Steele, 1985).

Differences in soil fertility influence the amounts of N, P and K taken up by maize plants but do not markedly affect the seasonal patterns of uptake and distribution

of these elements in the plant (Hanway, 1962). However, management practices, e.g. the time of application of fertilizer N, will influence the pattern of nutrient accumulation consequently fertilizer applications should be timed to take account of plant demand for various nutrients. Under conditions of adequate soil N, N uptake by maize continues from emergence to maturity (Berger, 1962; Hanway, 1962; Thom and Watkin, 1978), with a maximum rate of uptake occurring during the period of intensive vegetative growth prior to tasselling when it may exceed 4 kg/ha/day (Thom and Watkin, 1978). Sufficient supplies of nitrogen are very important for the vegetative growth of the plant, producing a healthy green colour and luxuriant, sturdy growth (Schrimpf, 1966). Generous nitrogen fertilization increases the protein content of the grain, and appreciably promotes the uptake of other nutrients (Duncan and Schaller, 1962).

Conclusions from published reports on hybrid response to N vary considerably. A difference in hybrid response is interpreted as a statistically significant ($P > 0.05$) hybrid x N rate interaction (Gardner et al. 1990). Brown (1986) studied two hybrids in 1979 and four hybrids from 1980 to 1983 at three N rates in Canada. The hybrids studied differed in their response to N in 1982 and 1983, but not in other years. Hybrid response to N also depended on the plant density. Hatlilgil et al. (1984) studied six hybrids at two N rates and two locations in Nebraska in a single year. In this experiment, the hybrids did not differ in their response to N. Similar results were obtained by Bundy and Carter (1988) in a study of five hybrids for two years in Wisconsin. Hybrids tested in two locations and two years in Iowa responded to N differently from one another (Fakorede and Mock, 1982), as did 20 single cross hybrids studied by Balko and Russel (1980) over six environments. In a later study which

included three hybrids, there were no differences in hybrid response to N (Russell, 1984). Work by Tsai et. al. (1984) studied three hybrids at a single location and concluded that the hybrids could be grouped into three distinct categories based on their response to N.

In New Zealand, Thom (1974) recorded significant differences in plant nitrogen percent in response to applied N. The uptake of N increased with the N rate. The N percent in the grain and in most other components increased with higher rates of N.

Results of the survey conducted in New Zealand during 1983/84 seasons (Underwood, 1985) among Waikato maize merchants showed that an average of 100 kg N/ha; and another 100 kg N/ha were applied by maize growers as pre-plant and sidedress fertilizer, respectively. In an earlier survey (1982-83), Steele (1985) found that an average of 116 kg N was applied to maize crops. N concentrations in the ear-leaf on 36 properties survey ranged up to 4.2% and 30 crops (83%) had N concentrations associated with over 95% of maximum yield. These crops had apparently received more N fertilizer than was required for maximum economic return (Steele, 1983). Similar results were obtained in a survey conducted in the Waikato where 75% of the crops had N concentration associated with over 95% of maximum yield (Steele, 1983).

It is well accepted that fertilizer N recommendations should be based on individual field soil tests. However, general fertilizer recommendation are usually provided to give maize producers guidance. Steele (1985) recommended maize be sown with a starter fertilizer containing a minimum of 20 kg/ha to help early growth of maize

crops. Subsequent applications should then be made based on the results of soil and/or tissue analysis.

Phosphorous promotes development of flowers, grain formation and ripening, and is also important for root development (Schrimpf, 1966). Its accumulation patterns follows vegetative growth except that it is more rapid early in the season (Hanway, 1962).

Research results indicated that maize yields are increased by P fertilization on low testing soils (Rehm et.al. 1981; Webb et. al. 1992). This prompted many crop producers to increase or build-up available soil P to high concentrations, in expectation of high profits (Mallarino and Webb, 1995). However, several researchers have shown that the yield response of maize to P fertilizer is usually small or non-existent when soil test P values are higher than 15 to 20 ppm by the Bray-1 method (Mallarino et. al. 1991; Mallarino and Blackmer, 1992; Webb et. al. 1992). Similarly, Robinson and Murpy (1972) reported that phosphorous application did not significantly alter yield or quality of forage maize. Therefore ,it is likely that many producers are applying unneeded P fertilizer and are reducing the profitability of maize production (Mallarino and Webb, 1995).

In a fertilizer study conducted by Rehm et. al. (1981), a consistent curvilinear relationship between silage yield and rate of fertilizer P was observed. The application of fertilizer P at 22-33 kg/ha was sufficient to produce maximum silage yields on soil with a near neutral pH and relatively low levels of N, P and S.

The most popular phosphatic fertilizer in New Zealand is 15% potassic potassic superphosphate (Underwood, 1985). Pre-plant application at an average rate of 464 kg/ha was applied. This rate of phosphorous application vastly exceeds the requirements of the maize plant (Steele, 1985). However, comparison with rates of 900 kg/ha used five years previously showed some progress had been made toward more economic fertiliser application.

Recommendations for fertilizer P in New Zealand are generally based on soil test informations and is summarized as follows (Steele, 1985):

- | | |
|--------------------|--|
| Olsen P test > 14 | Do not apply pre-plant P. Apply 20 kg P/ha in starter |
| Olsen P test 11-14 | Do not apply pre-plant P. Apply the amount of P in starter that will replace the P removed in grain. |
| Olsen P test <11 | Apply 50 kg P/ha pre-plant and 20-35 kg P/ha in starter depending on expected yield. |

The crop yield response to pre-plant P falls as the soils test value increases so that the replacement of P removed in a 12 t/ha grain crop (40 kg P/ha) becomes uneconomic when the Olsen P test rises above 15. Yield is depressed when pre-plant P is applied to soils with an Olsen P test above 22 (Steele et. al. 1981).

The rate of K accumulation exceeds that of N and dry matter during early growth stages but unlike N and P, K accumulation reaches a maximum before ear formation when about 60% of total dry matter has accumulated (Sayre, 1968). Schrimp (1955) reported that maize makes heavy demands on potash where main significance is in the

maintenance of normal physiological functioning of the cells.

Research on potassium (K) requirements of maize grown for silage is scarce. Rhem et. al. (1981) observed that the effect of K was variable. In this study, the application of fertilizer K had no effect on dry matter production in two years out of five, a linear increase in one year while in the remaining two years, a quadratic effect was observed. On the other hand, Perry et. al. (1972) reported that application of 339 kg/ha of K resulted in increased dry matter yields of 32% and 21% in two consecutive years.

Recommendations for fertilizer K in New Zealand are also generally based on soil test information. Response to fertilizer K in New Zealand trials have been rare (Douglas et. al. 1972; Steele et. al. 1981) and regular application of K is not recommended unless the K soil test is less than 5. However, where previous crops have lodged badly or suffered from stem rot, K fertilizer application at an average of 56 kg/ha (Steele, 1985) may be considered since K has been implicated in preventing lodging and stem rot in maize and may counteract the effects of excess or unbalanced N supply (Kockler, 1960; Murdoc et. al. 1962). N fertilizer policies, should, however be reviewed before application of K.

Increasing production costs during recent years have adversely affected the profitability of maize production. Fertilizer inputs alone represent more than 20% of the cost of producing a maize crop (Hardacre et. al. 1991). There is an increasing requirement in nutrient uptake and utilization of crop be as efficient as possible, to

reduce the cost of production and achieve a higher profit for the farmer. To achieve this, it is very important to understand the concept of nutrient use efficiency.

Nutrient efficiency refers to the amount of dry matter produced per unit of nutrient applied or absorbed (Fageria, 1992). High nutrient efficiency may be due to greater absorption of the nutrient or to greater yield per unit of nutrient absorbed. In order to achieve high nutrient efficiency, it is important to understand the environmental factors such as soil, climate and plant affecting uptake of nutrients and utilization. Nutrient efficiency is classified into three groups, namely: agronomic efficiency, physiological efficiency, and apparent efficiency each calculated using different equations (Craswell and Godwin, 1984; Fageria, 1992). Agronomic efficiency is defined as the economic production per unit of nutrient applied while physiological efficiency refers to the biological production obtained per unit of nutrient absorbed. On the other hand, apparent recovery efficiency is the quantity of nutrient absorbed per unit of nutrient applied.

2.5.3 Hybrids

Hybrid maize and modern crop management practices have revolutionized the major maize production regions in the world (Jugenheimer, 1958). In the United States, the breeding for maize hybrid development began in the early 1900's. Hybrid maize seed first became available to growers in the USA in the 1920's to 1940's with the introduction of commercial double cross maize hybrids (Tollenaar et al. 1994). Since then, there has been a dramatic increase in maize grain yields in temperate regions of

the world with more than 50% of this gain attributed to the use of hybrid seed (Russel, 1974; Duvick, 1977; Castleberry et. al. 1984). The average rate of yield improvement during the past three to five decades of approximately 100 kg/ha/yr has been recorded for temperate environments of North America and Europe (Edmeades and Tollenaar, 1990). This is equivalent to approximately 1.5% per year (Tollenaar et. al. 1994). The annual average maize yield improvement in tropical countries has been 43 kg/ha/yr. (Edmeades and Tollenaar, 1990). Yield improvement has been the result of genetic gain, changes in cultural management, climate and the interactions among these factors (Tollenaar et. al. 1994).

Growers throughout temperate regions, including New Zealand, are able to select from a range of hybrids suited to their specific growing environment and production requirements (Connel, 1985). These hybrids differ in grain yield potential, maturity, standability, grain drying rate and resistance to pests and diseases. The best hybrid cultivars produce high yielding, uniform crops under favourable soil and climatic conditions while maintaining better yields than older hybrids or open-pollinated varieties under unfavourable conditions (Castleberry et. al. 1984).

Hybrids are produced by crossing together inbred lines until desirable characteristics are found (Jugenheimer, 1958). Inbred lines are lines which have been self-pollinated (crossed with themselves) for 5-7 generations to produce genetic uniformity which can be expected to perform in the same way each time it is grown under the same environmental conditions (Jugenheimer, 1958; Connel, 1985).

Several types of hybrid are possible (Table 1) , depending upon the number and arrangement of the parental inbred lines. These include single, three-way, double, multiple, top, and back crosses .

The simplest hybrid, known as single cross is produced by combining two inbred lines. Single crosses tend to be slightly higher yielding and more uniform in plant and ear characteristics than other hybrid types. The single cross is used extensively for commercial sweet corn production where uniformity is of extreme importance. High cost of seed is the principal objection to single crosses for field production. It is worth mentioning that the second acceleration of corn yield improvement in the United States was associated with the replacement of double cross by single cross hybrids in the 1960's. (Tollenaar et. al. 1994).

Seed of three-way crosses is less expensive to produce than that of single crosses but more expensive than that of double crosses. They tend to be more uniform and slightly higher yielding than double crosses (Jugenheimer, 1958).

Double crosses are the most widely used type of hybrid. Double crossed seed is produced on single-crossed plants which are highly productive of quality seed. Double crosses are slightly more variable in plant characters than single or three-way crosses (Jugenheimer, 1958).

Multiple crosses, involving six, eight or more inbred lines, have been used very little commercially. They may be useful under adverse conditions where lower seed

Table 1. The arrangement of the parental inbred lines for different hybrid types (Jugenheimer, 1958).

Type of Hybrids	Pedigrees
Single Cross	$A \times B$
Three-way Cross	$(A \times B) \times (C)$
Double Cross	$(A \times B) \times (C \times D)$
Multiple Cross	$[(A \times B) \times (C \times D)] \times [(E \times F) \times (G \times H)]$
Top Cross	$A \times$ Open pollinated variety, or $(A \times B) \times$ open pollinated variety
Back Cross	$[(A \times B) \times A] \times [(C \times D) \times C]$
Single-back Cross	$[A \times B] \times [(C \times D) \times C]$
Synthetic	Composite of many lines

costs or greater variability in the crop are important factors (Jugenheimer, 1958).

Top crosses are simple to produce and often are useful hybrids for use in early stages of a breeding program (Berger, 1962). They are temporary expedients which, usually, are eventually replaced by double crosses. They are also useful for evaluating the performance of inbred lines, and provide a means of selecting promising open-pollinated varieties for use as source material for the development of inbred lines.

Backcross hybrids are not being used extensively being complicated and expensive to produce (Jugenheimer, 1958). However, they may give excellent performance and reasonable uniformity of plant and ear.

Synthetics are produced by compositing selected inbred lines. Advanced generation seed of multiple crosses are termed "synthetic varieties". Synthetics are proving to be very useful reservoirs of desirable gene combinations for the development of superior inbred lines (Sprague, 1955; Schrimpf, 1966).

Maturity of hybrids is one of the major characteristics to be considered in selecting suitable maize hybrids (Duncan, 1966). Some hybrids must be extremely early in maturity in order to provide a high yield of sound grain within the limits of the growing season. Later maturing hybrids are needed in other areas to take full advantage of extremely long growing seasons.

Various measures of maturity are used by different workers (Jugenheimer, 1958).

These include:

- i) Days from planting or emergence to silking or tasselling.
- ii) Percentage of dry matter or moisture in the grain at harvest.
- iii) Days from planting or emergence to maturity.
- iv) Heat unit sum.

Aldrich (1943) defined maturity as the maximum dry matter accumulation in the grain. Shaw and Loomis (1950) used the term "physiological maturity" and found that the moisture content at maximum dry matter accumulation in the grain ranged from 28% for early hybrids to 40% in late hybrids.

Several researchers have reported that later-maturing maize hybrids have been found to produce the highest yields of grain and silage (Colville, 1966; Cummins, 1975; Larson and Hanway, 1977; Lutz et. al. 1971; Lutz and Jones, 1969; Norden, 1961). Some studies have shown however, that silage yields from different maturing hybrids were similar (Colville and McGill, 1962); other researchers have noted that longer season hybrids had higher grain yields (Alessi and Power, 1974; Andres and Peek, 1971; Bryant and Blaser, 1968).

In New Zealand, maize hybrids of USA relative maturity ratings (RM) of 80 to 120 days are used to make silage with the later maturity hybrids tending to give higher yields (Douglas, 1980). However, to make acceptable silage, a crop has to reach a threshold maturity (about 35% DM) within the growing season of a locality. For North

island maize growing areas, 110-120 day RM maize hybrids fill the growing season (Cumberland et. al. 1971; McCormick, 1971). Quicker maturity hybrids have their place for late sowings, where early crops are desirable so autumn crops can be established, or in South island situations where the growing season is shorter (Jagush and Hollard, 1974; Menalda and Kerr, 1973). In general, while later maturing hybrids dominate as silage crops, there is much less difference in yield between quick maturing and full season hybrids in early growth (Jagush and Hollard, 1974).

2.6 MAIZE SILAGE

Forage maize is grown for ruminants which produce meat and milk. The value of the crop is partly determined by the efficiency of the conversion of forage to animal product. This conversion is affected by the digestibility of the forage, the animal's intake and the efficiency of feed utilization (Deinum and Struik, 1986). These factors are interrelated and all are influenced by both animal and plant characteristics. Whole-crop maize silage is attractive to farmers for the following reasons:

- i) its high content of energy for lactation (6.5 -6.8 MJ/kg) achieved by high digestibility of organic matter and
- ii) by reaching a dry matter content at maturity of 30% or more (Zimmer, 1981). If both conditions are met, a minimum in conservation losses and a maximum in feed intake is achieved (Zimmer and Wermke, 1986).

There are three combining factors responsible for the extensive utilization of maize silage and maize grains as major feeds in the United States and Europe for dairy

and cattle. These are: (i) the need to house stock under climatic extremes; (ii) the increasing demand in quantity and quality of animal products and (iii) the need to programme supply of these to large markets (Taylor, 1975). In New Zealand, the pastoral based systems produces marked fluctuations in seasonal dry matter yield despite the presence of temperate maritime climate. Feed deficiency in winter and summer affects the health and production of livestock and disrupts the killing, processing and transport industries.

A knowledge of the appropriate criteria for assessing nutritive quality of forages particularly maize is important in establishing its contribution towards meeting an animal's needs. This depends upon the nutritive composition of forage, the rate of animal intake and the efficiency with which animal uses the ingested nutrients. From a practical standpoint, the growers should consider the various aspects of production, harvesting, storing and feeding which may influence the value of maize silage. However, this review will cover only on aspects related to production practices of maize silage including its nutritive/quality characteristics.

2.6.1 Factors Influencing Components and Composition of Maize Grown for Silage

2.6.1.1. Plant Maturity at Harvest

Maturity at harvest is recognized as an important factor determining the quality of maize harvested for silage (Cummins, 1970). It affects maize silage quality because it influences grain and moisture content as well as stover digestibility (Holland and

Kezar, 1990).

Determining the maturity of maize for whole plant silage has been the subject of much research in the past. Since the early 1970's, the appearance of black layer was the stage commonly recommended for harvesting maize silage (Daynard, 1972). The blacklayer development in the placental region of the kernel indicated that grain had reached maximum dry matter accumulation (Daynard and Duncan, 1969; Rench and Shaw, 1971). Afuakwa and Crookston (1984) and Crookston and Kurle (1988), demonstrated that kernel milkline (ML) position was a more reliable and useful visual indicator of grain maturity and optimum dry matter content for ensiling and recommended that the timing of silage harvest be made between half-milkline (HM) and blacklayer (BL) formation. Subsequently, Hunt et. al. (1989) suggested that whole plant corn be harvested when the milkline is between $1/2$ and $2/3$ of the distance from the top of the kernel. The whole plant at this maturity would be at a nutritional value plateau and would typically be at a suitable moisture content to allow for safe storage.

Unlike grain, the forage portion of the plant is subject to decreasing quality with maturity. Digestibility of organic matter and cell walls (Wilkinson et. al. 1978) and gross energy (Goering, et. al. 1969) of whole plant maize declines with maturity. Increased proportions of grain in the whole plant are negated by decreased *in vitro* (Daynard and Hunter, 1975; Weaver et. al. 1978) and *in vivo* (Johnson and McClure, 1968) digestibilities of the stover as the corn plants matures. Cummins (1970) found that the *in vitro* dry matter digestibility (IVDMD) and the total available carbohydrate (TAC) content of ears increased with maturity then levelled off, and reached a

maximum at dough stage. Plant maturity-associated reductions in corn silage feed quality (White et. al. 1970), milk production (St. Pierre et. al. 1983; 1987), and growth (Calder, et. al. 1977) are accelerated during frost conditions.

2.6.1.2. Hybrid Selection

Hybrids planted for silage have been selected according to their grain-yielding ability (Pinter, 1986; Fairey, 1980). This approach was based on research in the United States in the 1930's and 1940's by early maize researchers who reported that the best grain genotypes produced high yielding high quality forage at a dry matter content suitable for ensiling (Hunter, 1986). This premise have been accepted by maize breeders especially in countries where silage maize constitutes only a small proportion of the total maize area.

However, in areas where silage maize plays a greater role, maize researchers are questioning the view of selecting the best grain hybrids and using them for silage (Hunter, 1986). Gallais et. al. (1976) found differences between hybrids for yield of forage dry matter but found no relationship between the proportion of grain in the forage and total DM yield. Their conclusion was that all parts of the plant must develop in order to obtain highest yields. Stalk height, stalk diameter and leaf size have all been reported to be related to yield of forage dry matter (Gallais et. al. 1976; Craig, 1966). Vattikonda and Hunter (1983) investigated 81 maize hybrids for grain and silage performance for two years at two sites in Ontario Canada, found that the coefficient of determination between grain yield and silage yield was not large enough to permit

reliable selection of hybrids for silage production based on grain yield performance.

In the search for better silage hybrids, maize researchers reported several ideotypes of silage maize. Struik (1984) defined ideotype as the ideal genotype of a crop, in which the characteristics that maximize productivity and quality under the prevailing conditions and recommended cultural practice are combined. According to Struik (1984), these should be:

- (i) yield a maximum and stable amount of digestible organic matter;
- (ii) be easy to harvest and preserve;
- (iii) be palatable, nutritious and allow a high dry matter intake and
- (iv) be efficiently utilized by the animal.

When these demands are translated into model characteristics of forage maize for north-west Europe, Struik (1984) came up with the following traits:

- (i) high dry matter yield;
- (ii) low susceptibility to pests and diseases;
- (iii) stocky stem and superior root system;
- (iv) optimum component of cellular content;
- (v) low amount of cell-wall constituents;
- (vi) high potential cell-wall digestibility and a fast rate of cellwall digestion;
- (vii) sufficiently high dry matter especially in the stover;

- (viii) a certain proportion of ear in the dry matter and
- (ix) a moderate level of watersoluble carbohydrates (WSC) in the stover.

Struik (1984) concluded that the abovementioned characteristics are diverse and often contradicting making it impossible to combine them in one genotype and thus, the search for an ideotype is therefore the search a best compromise.

Hybrid selection is known to influence maize silage in three ways (Holland and Kezar, (1990):

- (i) yield of material harvested;
- (ii) grain content in the silage at harvest and
- (iii) digestibility of maize silage.

Deinum and Baker (1981) and Kezar (1989) demonstrated a large nutritional differences between hybrids selected and grown for maize silage. Their studies have shown that while grain content is important and can vary substantially from hybrid to hybrid (from less than 20% to over 50%), the digestibility of the stover portion of the plant (leaves plus stalk) can also differ considerably. Vattikonda and Hunter (1983) reported a range from 65.6% to 73.8% for in vitro dry matter digestibility in the stover portion of 40 different hybrids.

Maize silage yield is influenced by hybrid selection, as stated earlier. However, selection of hybrid of proper maturity for the area it is grown is also very important (Holland and Kezar, 1990). If the relative maturity is too short for the area, total yield

of maize silage will be reduced. Conversely, if the maturity rating of the hybrid is too long for the area, poor quality may result due to decreased grain content. In addition, moisture content at the time of harvest (too wet or too dry) may also be a problem if the proper maturity is not matched to the area.

In New Zealand, considerable research effort has been directed into maize growing for grain since the early 70's. While some of this research can be applied to growing maize for silage, there are still gaps in the information on growing, utilization, feeding value and economics of silage maize (Buxton, 1974). During this period, a very limited number of maize hybrids were available for silage crops and of those which were available, doubt was cast as to their suitability as they were originally selected for grain yield and not whole plant yield. The thinking was to use a hybrid which had the best grain yielding characteristics (Menalda and Kerr, 1973). Today maize hybrids are becoming available specifically for maize silage production. Some of these hybrids are included in this study for assessment of field performance and quality under Manawatu conditions.

2.6.1.3. Plant Population

Plant population is defined as the number of plants per unit area. It has a very marked effect on crop yield and is regarded as an "agricultural input" in much the same way as is fertilizer (Willey, 1982).

The effect of plant population on maize yield has been studied extensively, probably because the yield response to plant density varies substantially with maize genotype, management practices, location and year (Tollenaar et. al. 1994). Yield increases with increasing plant density up to a maximum for a maize genotype grown under a set of particular environmental and management conditions and declines when plant density is increased further (Duncan, 1958) and or remains reasonably constant (Willey, 1982). On a per plant basis, the mean yield decreases as plant population increases due to increasing competition for growth resources. However, on an area basis, the increased plant numbers gives greater utilization of resources and total biological yield increases in the form of a diminishing response curve that levels off when plant population is sufficiently high for maximum resource utilization (Willey, 1982). This type of response curve is exemplified by the dry matter yield response of maize to plant density (Adelana and Milbourn, 1972a; Iremiren and Milbourn, 1978; Pinter et. al. 1994). On the other hand, maize grain yield response to plant density is parabolic (Tollenaar, 1989). As a result, the optimum plant density for forage or silage production is higher than that for grain production (Lucas, 1986; Hunter, 1978; Phipps, 1980; White, 1976).

Many researchers have looked at the effect of plant population on maize silage yields (Bryant and Blaser ,1968; Colville and McGill, 1962; Lutz and Jones, 1969 ; Rutger and Crowder, 1967). These studies have shown that as plant population increased, yields increased, reached a maximum, and then declined. In general, silage yields were maximized at a higher plant population than grain yields (White, 1976; Hunter, 1978; Phipps, 1980). At Ithaca, New York, dry matter yield increased as plant

density increased from 20,300 to 32,400 plants per acre (50,000 to 80,000 plants per hectare) with no significant reduction in harvest index (Graybill et. al. 1991). High dry matter yield occurred at 32,400 plants per acre. In the Piedmont region of Georgia, dry matter yield increases as plant density increased from 27,500 to 34,800 plants per acre (67,900 to 85,900 plants per hectare) while ear content decreased from 55 to 45% and stalk proportion increased from 27 to 32% (Cummins and Dobson, 1973). Recently, Jones et. al. (1995) concluded that dryland maize silage fertilized with 160 lb N/acre (180 kg/ha) and grown at a plant density of 29,000 plants/acre (71,600 plants per hectare) produced the optimum dry matter yield and profit. However, the optimal population varied with climate, soil, hybrid and management differences (Knapp and Shaw Reid, 1981).

Several researchers have noted that for early hybrids, the optimal population was higher than for later hybrids (Brown et. al. 1970; Hunter et. al. 1970; Rossman and Cook, 1966). This difference has been attributed to the smaller plant size and lower leaf area of most early hybrids. Andrew and Peek (1971) found that the optimal population is higher for earlier planting than for late planting. High plant populations have been shown to delay maturity somewhat in some studies (Rossman and Cook, 1966; Rutger and Crowder, 1967); in other cases it did not (Lutz et. al. 1971).

Studies looking at the effect of plant population on yield and quality of maize silage, have produced conflicting results. Fischer and Fairey (1982) studied plant populations of 24,292 and 40,486 plants per acre (60,000 and 100,000 plants per hectare). At harvest, the dry matter and ear contents were 24.2 and 34% and 22.8 and

28% for the low and high density populations, respectively. Dry matter intake and milk production were higher for the low population maize silage while milk fat percentage was lower. Silage yields were not different between the two population treatments. A three year comparison of maize silage with final average populations of 23,482 and 49,595 plants per acre (58,000 and 121,000 plants per hectare) was conducted by Nicholson et. al. (1986). High plant populations produced highest silage yields. Over the three year period, lower apparent digestibilities were observed with the high population silage and a reduction in average daily gain of beef cattle was noted. The high population maize however increased beef production per unit area of land.

The harvest index of mature grain crops is the ratio of economic product (grain) to the above ground biomass at harvest (Fageria, 1992). It estimates partitioning of the dry matter between the grain and the stems and leaves (Snyder and Carlson, 1984). Allen (1992) reported that in a normal year, about half (40 to 55%) of the dry matter of maize silage is from grain, a highly digestible plant component. This was concurred by Hay (1995) who reported that harvest index of commercial hybrids was considered unique among major world crops as its index was already high even at the start of the century. Thus, the open pollinated types used in the USA up to the 1920's had values of around 0.45 (Russel, 1991). In North America, selection of hybrids adapted to intensive cultivation (high population density; high soil fertility; pest and disease control) has resulted in very substantial increases in grain yield potential mainly caused by increased biomass rather than increased harvest index, which has remained relatively stable (Hay, 1995).

The effect of population density and relative maturity rating on HI of maize has been tested to a limited extent (DeLoughery and Crookston, 1979). When densities were increased, especially above the level at which grain yield was maximal, HI decreased (Adelana and Milbourn, 1972b; Fery and Janick, 1971; Genter and Camper, 1973; Voldeng and Blackman, 1975; Deloughery and Crookston, 1979; Dwyer et. al. 1991). Early maturing maize hybrids tends to have higher indices than later maturing hybrids (Adelana and Milbourn, 1972b; Bonciarelli and Monotti, 1975; Bryant and Blaser, 1968).

The findings of researchers working under different climatic conditions differ about ideal harvest index due to differences in light intensity and temperature (Pinter, 1986). Perry and Caldwell (1969) and Bunting (1975) working on sterile maize plants found that there was no need for grain because assimilates were stored in the vegetative parts in a form with similar digestibility as in the kernels. Smith et. al. (1978) and Fisher et. al. (1968) emphasize the importance of a large proportion of kernel. A high grain content within maize forage or silage imparts favourable ensiling characteristics, increases dry matter content and palatability, reduces seepage of soluble carbohydrates and protein in effluent and shelters total non-structural carbohydrates (TNC) from microbial attack (Phipps, 1980). Pinter (1986) reported that the ideal silage hybrid needs a grain fraction of at least 300 g/kg. High plant densities that increase leaf area index and dry matter yield may increase interplant competition which reduce the harvest index (HI) or grain portion of the forage (Duncan, 1984). The HI of recent hybrids, however, does not decrease at high plant densities (Tollenaar, 1989). As a result, plant densities as high as 10 plants m² have been reported to have no influence on HI or energy

content of the forage (Karlen and Camp, 1985).

Silage maize research in New Zealand started in the early 1970's. Menalda and Kerr (1973) reported a mean total dry matter yields of 16,500, 18600 and 15,400 kg DM/ha for three sowing dates planted at a mean population of 76,000 plants per hectare. Douglas and Dyson (1972) showed that with adequate available moisture, total plant dry matter yield continues to increase up to a population of 200,000 plants per hectare but with a declined in the proportion of grain beyond 90,000 plants/ha. Wallace and Davies (1976) conducted forage maize density trials comparing early sowing in October with conventional sowing time in November using 16 density treatments. They reported that forage yields from October sowing increase with increasing plant population giving a maximum yield of 25.5 tonnes/ha. The yield curve levelled out above 220,000 plants per hectare. On the other hand, a lower maximum yield of 19.0 tonnes/ha with a yield curve levelling out above 60,000 plants per hectare was obtained in the November sowing. Trials carried out by Edmeades (1972) concluded that silage yields were likely to be significantly reduced if full or late-season hybrids are grown at less than 25,000 plants/acre (61,750 plants/ha). Smaller earlier hybrids were recommended to be grown at more than 35,000 plants/acre (86,450 plants/ha). He added that hybrids intermediate in maturity be established at minimal population intermediate between 25,000 and 35,000 plants/acre. Thom et. al. (1981) showed that a significant increase in total dry matter yield at the "hard dent" stage was possible by increasing the established population to 166,000 plants per hectare with an associated small reduction (5-6%) in the proportion of plant dry weight as grain. It has to be mentioned that silage crops grown in New Zealand have been traditionally established at relatively low populations

(about 80,000 plants/ha) to maximize grain production (Thom et. al. 1981), because a high grain content in maize silage has been associated with better quality (Owen, 1967; Eddowes, 1969; Montgomery et. al. 1974). Finally, it must be noted that increasing yield by increasing the plant density, correspondingly requires an increased in seeding rates, thus consideration should be given to seed cost and other inputs needed in maize silage production (Thom, 1977).

2.7 NUTRITIVE VALUE OF MAIZE SILAGE

This section will consider important factors affecting nutritive quality and ensiling characteristics of silage maize.

2.7.1. Digestibility and Energy Value

The term digestibility describes that proportion of the feed useful for energy or protein to the animal. In Europe, it is normally expressed on the basis of either dry matter (DM) or organic matter (OM), and is commonly expressed as the percent of digestible organic matter in the dry matter (DOMD or D-value). In the USA and in some other countries, digestibility is often expressed as the percentage of total digestible nutrients (TDN). TDN refers to a measure of digestibility of nutrients contained within a feed that may be use as energy by the animal

Whole-plant forage maize is an important forage for many dairy and beef operations (Graybill et. al. 1991). The value of the maize silage crop is partly

determined by the efficiency of the conversion of forage to animal product (Deinum and Struik, 1986). This conversion is affected by the digestibility of the silage, the animal's intake and the efficiency of feed utilization. These factors are interrelated and all are influenced by both animal and plant characteristics.

Several investigations have evaluated maize silage digestibility and dry matter (DM) intake when fed to ruminants. Early work (Huber et. al.,1965) with lactating cows fed with maize silages of varying maturity (soft, medium and hard dough with dry matter content of 25.4, 30.3, and 33.3%, respectively) resulted in a significant increase in milk yields. This higher milk production was probably attributed to the increase in DM intake brought about with the advancing maturity of the silage maize. Digestibility research with sheep (Johnson and McClure, 1968) at eight stages of maize grain maturity indicated that the DM digestibility was significantly affected by maturity. Highest DM digestibilities occurred at the milk-early dough and dough-dent stages and decreased only slightly after this. Digestibility was 68% at the mature kernel stage. However, cellulose digestibility decreased significantly as the maize plant matured.

Goering et. al. (1969) studied intake and digestibility of maize silages of different maturities, varieties and plant population fed on steers. Their results indicated that significant differences in daily DM intake of the maize silage, expressed as a percent of body weight was due to differences in plant population and hybrid. The higher population maize silages had higher intakes than the low population maize silages. Average DM digestion coefficients for silage harvested at low DM contents (25%) was higher (67.8%) compared to the silage harvested at high DM contents (35%) with an

average DM digestion coefficient of 60%.

The composition, voluntary intake and digestibility of 66 maize silages were studied in sheep from 1968 to 1970 by Andrieu and Demarquilly (1974). They reported that there was no reduction in digestibility between standing and ensiled maize and only a slight decrease in the voluntary intake was observed; that between the milk and glaze stages of the grain, the stage of growth at harvest had a slight influence on the digestibility coefficient of the organic matter in the whole plant silages. The voluntary intake did not increase or tended to decrease when harvest was delayed. As there was almost no variation in the feeding value according to the stage of growth at the time of harvest, the optimum stage was determined mainly according to the dry matter production per hectare. The later was generally at the maximum when the DM of the plant reached 33-35% (glaze stage of the grain).

The differences in quality of component parts (ear, leaf, stalks) and whole plants of maize harvested as silage have been studied by several researchers. Daynard and Hunter (1975) found that as hybrids mature, stover quality and quantity decrease while grain quantity increased. Cummins (1970) showed that the *in vitro* dry matter digestibility (IVDMD) of ears increased with maturity and levelled off at later harvests. Maturity and IVDMD of ears were reported to be significantly correlated. This significant correlation was attributed to the increased carbohydrate accumulation by the ears, reaching a maximum before levelling off. The IVDMD of leaves decreased with maturity. The carbohydrate content during maturity was variable. This variability was probably due to fluctuations in daily synthesis and translocations of carbohydrates

caused by light, moisture and time of sampling variations. A different pattern for stalk IVDM was observed in the 3-year study. Stalk carbohydrates content followed the stalk IVDM curves closely. The quality of the whole-plant maize silage reflected the differences observed in the quality of different maize plant components. These results are similar to those of Leask and Daynard (1973) who found a wide range of IVDM for the leaf, stalk and husk components of maize hybrids under study.

Increasing digestibility to improve quality is a major objective in forage improvement (Buxton and Casler, 1993). Significant genetic variation has been demonstrated among maize hybrids for whole plant in vitro digestible dry matter (IVDDM) (Leask and Daynard, 1973; Gunn, 1978; Vattikonda and Hunter, 1983; Hunt et. al. 1992). However, in most investigations, maize stover IVDDM varied more than maize grain or whole-plant IVDDM (Vattikonda and Hunter, 1983; Pinter et. al. 1986; Wolf et. al. 1993 a,b). Wolf et. al. (1993b) found that whole-plant grain content and stover digestibility are independent of each other and that both influence whole-plant digestibility. Dhillon et. al. (1990) concluded that "the presence of significant genotypic variation indicates that it should be possible to select for better stover IVDDM".

Schaefer (1984) reported that of the gross energy, about 4.4 Mcal per kilo DM (18.4 MJ/kg DM), 65-70% is actually digested by ruminants. The digestibility depends on the stage of maturity of the maize, the ear content, losses during ensiling and the feeding rate. Of this, digested energy, about 15% is lost with the urine or as methane. The resulting metabolizable energy (ME) is therefore about 10.5 - 10.9 MJ/kg DM.

The efficiency of utilization of the ME of maize silage for milk production is approximately 60% and for beef 50-55% (Schaefer, 1984). The net energy derived from maize silage and used for milk production is therefore about 6.28 MJ/kg DM. In the US, this value is 7.1 MJ/kg DM (USDA, 1971) which, expressed in total digestible nutrients (TDN), is equivalent to a value of 70.

Pinter et. al. (1990) reported that low whole-plant digestibility was associated with decrease in harvest index (HI), grain being the most digestible plant part. A decrease in HI was a result of increasing plant population (Hunter, 1978; Daynard and Muldoon, 1981; Phipps et. al. 1981). In trials with 7.5 and 10 plants m^{-2} , at two locations in Canada, Fairey (1982) found that digestibility of whole-plant maize DM was significantly but not closely ($r=0.28$) related to harvest index. Stover digestibility was inversely correlated ($r=-0.45$) with harvest index, indicating that the nutritive value of the stover declines with increasing grain growth. He further found that population density had no influence on whole plant DMD. Struik and Deinum (1982) studied the effect of light intensity after flowering on the quality of silage maize planted on three population densities (5, 10 and 15 plants m^{-2}) in the Netherlands. They found that in vitro digestibility of the organic matter of the whole crop was affected most by shading during the last part of the growing season and decreased as the plant population was increased.

2.7.2. Protein Content and Minerals

The concentration and yield of protein in maize grain is one of the major factors in determining its feeding value (Bullock et. al. 1989). Maize protein concentration will vary due to soil N (Pierre et. al. 1977), soil K (Keeney, 1969) and climatic conditions (Bird and Olson, 1972; Earle, 1977), but genetic constitution has the largest effect (Alexander and Creech, 1977). Thom (1981) reported that mineral content of maize, especially N and K increased during vegetative growth (up until about 110 days from sowing) as a result of mineral uptake exceeding growth. Earlier, Johnson et. al. (1966) found that prior to tasselling, maize plant resembles other forage plants with a relatively high of protein in the leaves which declines steadily until maturity. The stalks had a protein content of between 11 and 12% prior to tasselling and declined rapidly until 15 days after tasselling, then declined slowly throughout the remainder of ear growth to maturation. They also observed that the protein content of the ears followed the pattern of the leaves until the final stages of maturity when it tended to increase.

In general, the protein % of maize silage is consistently below animal requirements (Crampton and Harris, 1969; Eberhard et. al. 1980; Smith, 1982). Because of this, the effective use of maize silage in all types of livestock production depends on combining other feedstuffs with maize silage to correct its inherent deficiencies (Barry et. al. 1980). The importance of the deficiencies and the choice of feedstuffs to correct them vary with the type of livestock and the values of animal products and feedstuffs.

Buxton (1975) and Smith (1982) recommended that at least 20-25% and 25-30%, respectively of the ration should be pasture to avoid protein deficiency. Adding urea at about 5 kg/t at the time of ensiling or adding natural forms of protein such as meat meal, lucerne meal or soybean meal at the time of feeding will also overcome protein deficiency. However, these methods are very expensive compared to pasture. In a feeding study, Waghorn and Wilson (1974) used maize silage as a sole ration and in conjunction with fresh pasture for cattle. They concluded that the protein deficiency of maize silage could be overcome by supplementation with small quantities of fresh pasture; higher levels of supplementation resulted in very high intakes of digestible nutrients.

Maize silage is also low in some important minerals (Linton , 1975; Taylor, 1975; Buxton, 1975) especially when fed to cows in early lactation. It is low in calcium, phosphorous, magnesium, sodium and some trace elements.

2.7.3. Fibre Content and Fibre Digestibility

Carbohydrates are divided into two main types, non-structural and structural (Phipps and McAllan, 1984). Soluble sugar are the main non-structural carbohydrates present in maize. The major structural carbohydrates which are called cell wall fractions are cellulose, hemicellulose lignin and silica. A typical composition, digestibility and energy value of European forage maize is shown in the Table 2.

Table 2. Typical composition, digestibility and metabolizable energy value of forage maize at the time of harvest. Crop DM content 28%.

Composition	% of DM
Non-structural carbohydrates	40
sugars (WSC)	15
starch	25
Structural carbohydrates (cell walls)	46
hemicellulose	18
cellulose	23
lignin	5
Protein	9
Ash	5
Digestibility in vivo (%)	
DM	75
Organic Matter	74
OM in DM (DOMD)	70
Metabolizable energy value (MJ/kg DM)	10.8

WSC - Water soluble carbohydrates

Source: Wilkinson, 1978.

The cell wall fraction which is the insoluble portion of the forage is normally expressed as neutral-detergent fibre (NDF). This NDF has been shown to be negatively correlated with dry matter intake (Holland and Kezar, 1990). NDF increases with advancing maturity.

The fraction of the forage that is most commonly isolated and reported is the acid detergent fibre (ADF). ADF differs from NDF as it provides an estimate of the combined cellulose and lignin contents. ADF is the portion of the forage that remains after treatment with a detergent under acid conditions. Maize silage with lower ADF values have a higher energy content and are desirable. ADF is important because it has been shown to be negatively correlated with the digestibility of forage. As the ADF increases, the forage becomes less digestible. Wallace and Davies (1976) found that the ADF values of total DM yield were unaffected by density for early sown hybrids using populations ranging from 50,000 to 300,000 plants/ha. They observed a slight but non-significant increase in ADF for late sown hybrids.

NDF and ADF concentrations of maize silage can be extremely variable (Allen et. al. 1992). Fibre values ranged over 10% of DM for ADF and 12% of DM for NDF for maize silage. Environmental conditions during maize growth can affect fibre concentrations and fibre digestibility greatly and both are affected by hybrid. Maize fibre content can be greatly influenced by nitrogen fertilization and maturity, however management factors such as population and planting date have been shown to have little effect. Understanding the factors affecting forage quality and variation in forage quality will help enhance production and profitability.

2.7.4. Maize Silage Moisture Content

Dry matter percent has a significant effect on silage quality (Wiersma et. al., 1993). Ensiling forages that are too wet (< 30% DM content) results in losses due to poor fermentation patterns and excessive seepage, while ensiling forages that are too dry (> 50% DM) increases the potential for heat damage and mould problems (Vetter and von Glan, 1978). Silage preserved between 30 and 40% DM content provides acceptable fermentation, preservation and animal performance (Lusk, 1978).

Ensiling maize with a DM content of 15-25% probably results in losses similar to those associated with the ensiling of any direct-cut perennial forage (Miller and Clifton, 1965; Castle and Watson, 1973). Nash (1978) reported approximate maximum effluent losses of 45, 125 and 300 l/t of forage at dry matter contents of 25, 20 and 15%, respectively.

Kaiser (1984) mentioned that unless, the forage has a high sugar content and low buffering capacity, wet forages are usually difficult to ensile because they generally promote the development of a clostridial fermentation. Clostridia are undesirable silage organisms that reduce the nutritive value of silage, preferring moist conditions for active growth. High moisture content also dilutes the solution concentration of plant sugars, slowing the decline in silage pH, again a factor which favours clostridia growth. These adverse effects on silage fermentation are responsible for the generally poor animal performance on high moisture silage. Another major problem which arises from

the ensiling of wet forages is that of silage effluent. It can be responsible for substantial losses of DM and energy (Kaiser, 1984). Sugars, nitrogen, minerals and silage fermentation products can be lost in the effluent. The loss of sugars can be critical, as it may determine whether a lactate or a clostridial fermentation occurs. Another serious problem with silage effluent is its polluting capacity. Woolford as cited by Kaiser (1984) reported that silage effluent has a biological oxygen demand value approximately 180 times higher than domestic sewerage, so necessary steps must be taken to ensure that it does not enter water courses.

2.8 ACCUMULATION AND PARTITIONING OF DRY MATTER IN MAIZE

The aim of crop production including maize silage, is to maximize the yield and quality of those plant organs which are of economic importance. These yields depend on the total dry matter present at harvest and on the dry matter distribution over the plant organs (Gaastra, 1962). The dry matter production of a crop is the result of the net photosynthesis of the individual plants (Alberda, 1962; Biscoe and Gallagher, 1976). Net photosynthesis (P_n) being a measure of the net gain of dry matter (DM) of a community of plants relative to their leaf area is regarded as an indicator of mean photosynthetic efficiency (Williams et. al. 1965; Watson, 1952). It is expressed as the difference between gross photosynthesis (P_g) and respiration (R)(Gaastra, 1962):

$$P_n = P_g - R$$

Gaastra (1962) also mentioned that the respiration rate per plant and per day can be as high as 25 to 50% of the daily gross photosynthesis. This is related to the report

of Lambers (1987) where 50% of the photosynthates produced daily is lost in the respiration of various plant parts. For analyzing the productivity of maize crops, it is necessary to know the actual and optimum daily dry matter production per unit area and the actual and optimum patterns of DM distribution during the development of the crop. In this review, some aspects of DM distribution and its environmental factors that influence its partitioning by maize crops will be considered.

The distribution of DM over the various parts of the plant has been described many times as ratios, for instance as shoot:root-ratio or leaf:stem-ratio (Brouwer, 1962). A gradually changing ratio during the course of development indicates a growth rate of one favoured over the growth rate of the other.

Various investigations have been done on the study of the progressive accumulation and partitioning of DM in maize. Experiments on maize in which different groups of leaf laminae were removed or ears shaded shortly after silking was conducted by Allison and Watson (1966). They showed that most of the DM increase after flowering was produced by upper leaves. The top five, the middle four and the bottom six laminae accounted, respectively, for 26%, 42% and 32% of the leaf area duration of the laminae after flowering. The estimated contributions of the three groups to DM production by the laminae after flowering were about 40%, 35-50% and 5-25%, respectively. The sheaths provided about 20%, of the total leaf area and probably contributed about 20%, and laminae 80%, of the total DM produced after flowering. The contribution from photosynthesis by the ear was negligible, presumably because of its surface area was only 2% of that of the leaves. Leaf efficiency (DM produced per

unit area) decreased greatly from the top to the base of the shoot. When laminae were removed, the grain received a large fraction of the DM accumulated after flowering, less DM remained in the stem, and the photosynthetic efficiency of the remaining leaves was apparently increased.

Hanway (1962) found that differences in soil fertility resulted in different rates of DM accumulation but did not markedly influence the relative proportions of the different plant parts. Bryant and Blaser (1968) reported that the relative proportion of the different parts varied between an early and late hybrids but was influenced only slightly by differences in plant populations or row spacing. Adelana and Milbourn (1972b) also reported that the partition of DM between leaf laminae, stem and ears differed with early and late hybrids. More than 63% of the total shoot DM was contained in the ear (grain and rachis) in the early hybrids while the ear in the late hybrids contributed only 52%. Hanway and Russel (1969) grew 11 maize hybrids in the field for determination of DM accumulation in the different plant parts at successive stages of plant development. They found that the length of time from seedling emergence to 10th leaf fully visible was the same for all hybrids at 44 days, but the length of time from 10th leaf to silking and the length of time during which the grain increased in weight varied markedly among the hybrids at 16 to 30 days and 43 to 60 days, respectively. The daily rate of DM accumulation was similar for all hybrids. The relative proportion of grain and non-grain plant parts varied among the hybrids. DM apparently accumulated in many nongrain parts of the plants after silking and was later translocated to the grain. In the subsequent year, Genter et. al. (1970) published their study of maize development at several stages of maturity to show further evidence of

translocation of nutrients as ears develop. Data obtained in this study showed that total dry weight increased from milk (12.91 t/ha) to the soft dough (18.16 t/ha) stage of maturity, but there was only a small and non-significant increase at maturity (18.60 t/ha). Ear weight increased significantly at each of the four successive harvest dates, increasing from 8.30 t/ha at the soft dough stage to 10.56 t/ha when mature. Leaf, husk and stem weights decreased significantly from the milk to the mature stage. Husks, upper leaves, and upper stalks showed the greatest decreases. The data indicated that most of the ear weight increases after the soft dough stage resulted from translocation of nutrients from other parts (Hanway and Russel, 1969).

The work reported by Adelana and Milbourn (1972b) on three maize hybrids grown in southeast England showed that a large decline in stem DM of between 35 and 48% occurred. This considerable remobilization of photosynthate coincided with the period of rapid ear fill during which approximately half of the final DM in the grain portion of the ear is accumulated. This confirms to the earlier findings of Daynard et al. (1969) who showed that there is marked remobilization of DM from the stem making a significant contribution to the grain yield during the second half of the grainfill period. This transference of DM did not commence until 2-3 weeks after silking when an adequate ear sink had been established, and thereafter the steady decline in stem weight due to the enlarged sink capacity of the ear or to the reduced effectiveness of the leaf canopy towards the end of the growing season. Phipps and Weller (1979) also found that stem yields decline after reaching a peak 2-3 weeks after mid silk. They explained this reduction to the movement of water soluble carbohydrates from the stem to the ear, with greater movement being associated with a larger ear component.

An investigation on the accumulation and utilization patterns of soluble solids in maize stalks was conducted by Hume and Campbell (1972). They observed that soluble solids in stalks in two short-season maize hybrids accumulated until 2-3 weeks after anthesis, and then declined rapidly during the grain-filling period. Most of the soluble solids that accumulated and disappeared were in internodes below the ear. When pollination and grain development were prevented, total soluble solids in stalks increased until the end of the growing season, indicating that the decline in stalk soluble solids during grain filling was caused primarily by translocation of metabolites from the stalk to the grain.

According to Tollenaar (1977) and Tollenaar and Daynard (1978), the limitations to grain yield in maize not explained by unfavourable factors such as disease, nutrient status, moisture stress and lodging may be analyzed in terms of assimilate supply to the grain (the source) and the potential of the grain to accommodate assimilate (the sink). It seems that the reported results of sink and source of maize is mainly directed to a sink limitation (Tollenaar, 1977). Yamaguchi (1974) and Goldsworthy et. al. (1974) concluded that kernel sink capacity is the dominant limitation to grain yield in a tropical grown hybrids in Mexico.

2.8.1 Environmental Influence on DM Partitioning

Environmental factors are known to influence partitioning and DM accumulation (Snyder and Carlson, 1984). Thus, an understanding of environmental effects on partitioning is essential for developing crop management strategies.

2.8.1.1. Temperature

It is generally known that the optimum temperature for growth of roots and shoots differs in many species (Snyder and Carlson, 1984). Van Dobben (1962) also mentioned that the growth rate of plants shows great specific differences and largely depends on climatic conditions.

The response of crop DM accumulation to temperature can be analyzed in terms of the temperature response of the processes underlying crop growth i.e. duration of development, net canopy photosynthesis, and DM partitioning (Tollenaar, 1989). In maize, rate of development (i.e. the inverse of duration of development) and leaf photosynthesis show a curvilinear response to temperature, with maximum at approximately 31°C (Duncan and Hesketh, 1968; Tollenaar et. al. 1979).

Most research that has been reported on DM distribution during vegetative development of plants has focused on root:shoot partitioning (Tollenaar, 1989). Brouwer (1962) postulated a functional balance between carbon assimilation by the shoot and nutrient and water absorption by the root: resources (i.e. assimilates) are allocated according to the highest rate of return (i.e. rate of DM accumulation).

Reported research results on DM partitioning during vegetative development have also frequently had treatment responses that were confounded with phenology and rate of DM accumulation (Tollenaar, 1989). Potter and Jones (1977) reported on the response of leaf area partitioning to temperature in various plant species. In their study, stage of

development at which the temperature treatment was applied may have varied by as much as 50%. However, substantial changes in DM distribution, in particular, during early phases of development, have been reported for maize (Hunter et. al. 1977). Rate of DM accumulation may also have an impact on DM partitioning. The effect of DM partitioning on DM accumulation is particularly large during early phases of development, when mutual shading of leaves within the canopy is relatively small. Specific growth rate ($\text{kg kg}^{-1} \text{d}^{-1}$) is the product of net assimilation rate ($\text{kg m}^{-2} \text{leaf d}^{-1}$) and leaf area ratio ($\text{m}^2 \text{leaf kg}^{-1}$), and growth rate is directly related to partitioning of DM into leaf area when net assimilation rate is not altered by a change in leaf area (Tollenaar, 1983).

Tollenaar (1989) conducted a study to quantify the response of DM partitioning in maize to temperature during the period from planting to the 12-leaf stage. He found that the leaf area partitioning coefficient (LAPC) (i.e. increase in leaf area per unit increase in total dry weight) increased linearly with temperature in the 11 to 31°C range and declined from the 4- to the 12-leaf stage. The LAPC was associated with DM accumulation and as much as 50% of the variation in growth rates between hybrids were associated with LAPC. Further, his study demonstrated that DM partitioning varies substantially among temperature regimes and phases of development, and between ear hybrids, and that part of the response of DM accumulation to temperature maybe attributable to DM partitioning.

Temperature and photoperiod are known to affect leaf number (Tollenaar and Hunter, 1983; Warrington and Kanemasu, 1983a, 1983b), although magnitude of

responses varies considerably among various reports. According to Warrington and Kanemasu (1983c), the number of leaves formed on a determinate maize plant is dependent on two developmental processes which are both influenced by environmental factors such as temperature and photoperiod. These are firstly, determined by the rate of leaf production at the apical meristem, and secondly, by the time between sowing and floral (tassel) initiation. Duncan and Hesketh (1968) reported an almost linear increase in average leaf number of 3 leaves per 10°C increase in temperature for temperature regimes ranging from 15 to 36°C. Several workers have also examined the influence of temperature and photoperiod on final leaf number and found an overall increase in leaf number in response to an increase in mean daily temperature is observed (Hesketh et. al. 1969; Hunter et. al. 1977; Tollenaar et. al. 1979). Conversely, other studies reported that an increase in temperature may also result in a decrease in leaf number over all or part of the temperature range studied (Stevenson and Goodman, 1972; Bonaparte, 1975).

The reports on leaf number response to photoperiod are consistent and show that leaf number increases with an increase in photoperiod (Chase and Nanda, 1967; Hesketh et. al. 1969; Stevenson and Goodman, 1972; Gmelig Meyling, 1973; Hunter et. al. 1974; Bonaparte, 1975). Most maize genotypes show an increase in leaf number when daylength is extended, although genotypes differ in their day-length reaction; maize genotypes which are highly sensitive, intermediate and insensitive to daylength have been reported (Francis et.al. 1969; Francis et. al. 1972; Hunter et. al. 1974). In addition, when maize genotypes were studied over a wide range of photoperiods, no regular pattern in leaf number response was apparent (Hunter et. al. 1974).

2.8.1.2. Light

Biscoe and Gallagher (1976) mentioned the relevance, in studies of crop DM production of considering crop photosynthesis in terms of its response to light intensity. They distinguished four broad patterns of response in determining crop photosynthetic rate. First, in the response pattern found in a young crop where the row structure is still distinct and the leaf area index (LAI) is less than two. Plant leaves in this stage are strongly illuminated in bright light and crop photosynthesis is saturated at light intensities only a little higher than those for individual leaves. Therefore, on a sunny days early in the season, much sunlight is wasted.

The second response pattern occurs when the crop is composed of young, healthy leaves of sufficient area to intercept most of the available sunlight (i.e. LAI of 3 or more). At this time young leaves with high maximum rates of photosynthesis are present at the top of the canopy and the crop transpires freely as the soil contains plenty of water.

The presence of young leaves at the top of the canopy but with small amount of available water in the soil is the third response pattern. If the weather is dry and sunny, plant water stress results and canopy photosynthesis slows approximately in proportion to the degree of stomatal closure.

The fourth and last response pattern predominates gradually after ear emergence when the photosynthesis of leaves in the canopy slows due to ageing. This causes a

weaker response of canopy photosynthesis to bright light. Drought exaggerates the ageing effect by closing stomata and accelerating leaf senescence.

The upper limit of crop production in an environment with adequate water and nutrients is determined by the amount of incident solar energy, the extent to which this energy is absorbed by the crop surface, and the efficiency of the crop in converting light and CO₂ into biological and economic yield (Heichel and Musgrave, 1969). Pearce et.al. (1967) mentioned two major factors, namely: leaf area index (LAI) and distribution of leaf area within a maize canopy which determined total light interception, which in turn affects photosynthesis, transpiration and DM accumulation. Vertical distribution of leaf area is determined by leaf size, leaf angle and internode length. Mock and Pearce (1975) defined an ideotype of maize with a LAI greater than (>) 4 as one with stiff vertically oriented leaves above the ear and horizontally oriented leaves below the ear to maximize light interception by the entire canopy.

2.8.1.3 Water and Minerals

Almost every process occurring in plants is affected by water deficits. Burstrom as cited by Kramer (1963), stated that vegetative growth is particularly sensitive to water deficits because growth is closely related to turgor and loss of turgidity stops cell enlargement and results in smaller plants. He added that water deficits not only reduce the total amount of growth but they also change the pattern of growth. Classen and Shaw (1970a) mentioned that the moisture regime during the maize pre-silking period has been shown to be important for both the development of vegetative structures, which

later determine the DM producing capacity of the plant, and the development of reproductive structures. In their water deficits study on maize, they observed maximum reductions in total vegetative DM production of 15 to 17% resulted from water deficits approximately 3 weeks before 75% silking. A significant increases in the stalk weight occurred as a result of stress at late silking and very early ear stages.

Reported results on the sensitivity to short periods of water stress by maize is greatest at silking, followed by early ear vegetative stages in order of decreasing vulnerability (Claassen and Shaw, 1970b). Several authors observed a reduction in grain yield greater than 40% as a result of 4 to 8 days of wilt at silking. (Barnes and Wooley, 1969; Denmead and Shaw, 1960; Robins and Domingo, 1953). Reduction in yield from water deficits during the ear stage have ranged from 21% (Denmead and Shaw, 1960) to 48% (Barnes and Wooley, 1969). During the vegetative stage, a 25% yield reduction from two stress cycles totalling 8 days of wilt were observed by Denmead and Shaw, 1960). Schussler and Westgate (1994) reported that water deficits during anthesis cause maize kernels to abort soon after fertilization. Water deficit resulted in decreased kernels per ear, ranging from 45 to 72%.

Donald and Hamblin (1976) stated that cereal crops suffering water stress not only have lower biological yield (i.e. the total yield of plant material) and grain yields, but also lower harvest indices. The study of Doss (1974) of maize in Alabama showed that the harvest indices were 0.465, 0.459 and 0.338 for the non-irrigated crop in 1970, 1971 and 1972, respectively and 0.477, 0.502 and 0.473 for the irrigated crop, with an average of 48% increase in grain yields. As the water supply become available

through irrigation or other sources, both harvest index and grain yields increased.

2.8.1.4 Plant Population Density

Plant densities can be selected to complement environmental factors that will produce the greatest economic yield per hectare. As a general rule, yield of above-ground biomass will be greater for high-density stands than for low-density stands (Snyder and Carlson, 1984).

Biological yield increases with plant density to a maximum value determined by some factor of the environment and at higher densities tends to remain constant (Donald and Hamblin, 1976). This response, termed an asymptotic relationship has been reported by many maize researchers (Bunting, 1971; Adelana and Milbourn, 1972a; Phipps, 1975; Iremiren and Milbourn, 1978). However, the grain yield and plant density relationship is parabolic i.e. grain yield increases to a maximum value and declines as density is further increased (Bunting, 1971).

The weight of grain per plant decreases with increased population (Dungan et al., 1958) and significantly decreases the dry weight of ear, grain and cob (Phipps, 1975). Tollenaar (1992) in his study also reported a decline in grain yield per plant when plant density is increased and attributed this predominantly to a decline in kernel number and weight.

Wilson and Allison (1978) reported a considerable decrease in dry weight of the non grain component between days 98 and 131 after sowing at 6.15 plants m^{-2} compared to 1.27 plants m^{-2} and 3.70 plants m^{-2} . Their study implied either that much material was transferred from shoot to grain or that DM which normally goes to the shoot was diverted to the grain. Allison (1969) stated that any greater than normal transfer of material from leaves to grain, as well as intense mutual shading of leaves, because of the close spacing of plants, could have hastened the physiological ageing of leaves at high plant population.

Ear size (i.e. length and girth) and number play a significant role in determining a hybrid's yield potential at varying plant populations (Thomison and Jordan, 1995). A "fixed" ear hybrid is associated with a relatively determinate ear size that limits its capacity to compensate for variation in plant population. A "flexible" ear hybrid has an indeterminate ear size that can compensate for variation in plant population.

Increasing the plant population tends to retard plant development slightly (Dungan et. al. (1958; Rutger and Crowder, 1967). Iremiren and Milbourn (1978) found that high plant density delayed silking, being at 108, 110, 111 days after sowing at 5.5, 11 and 17 plants m^{-2} , respectively.

Tetio-Kagho and Gardner (1988) observed that plant height increased to a maximum and then decreased (parabolically) with increasing plant population, similar to the trends reported by Stinson and Moss (1960) and Early et. al. (1966). Plant height was greatest at 6 to 10 plants m^{-2} . Internode elongation (etiolation), due to shade effect,

is believed to be an auxin response based on the theory that there is photodestruction of auxin at high irradiance, which results in reduced plant height (Leopole and Kriedeman, 1975). The decrease of plant height at ultra-high plant populations is probably associated with limitations of minerals and water.

The number of tillers per plant decreases linearly as plant population increases (Tetio-Kagho and Gardner, 1988). Tillering is the response of the maize plant to environmental conditions, and appears to be highly controlled by the environment (Dungan et. al. 1958; Tetio-Kagho and Gardner, 1988). Williams and Etheridge as cited by Dungan et. al. (1958) listed four factors which favour production of tillers :

- (1) highly productive soil with adequate moisture supply;
- (2) a strain of maize having a high tillering habit;
- (3) thin spacing of plants and
- (4) a time of planting which favours for vigorous growth.

Tillers therefore, are more numerous at low than at high population levels and on more productive soils.

CHAPTER III

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

An experiment was conducted to determine the effects of hybrid and plant population on yield, nutritive value, dry matter partitioning and protein in maize silage at Frewens Block, Massey University, Palmerston North (40° 23'S), altitude of 33m. The soil type was a mottled, fine, sandy loam. Rainfall and temperature data during the growing season was recorded at AgResearch, 2 km distance.

3.2 PLANT MATERIALS

Seven maize hybrids covering a range of maturities were used in the trial (Table 1). All but one of the hybrids were selected from the recommended lists of maize silage hybrids for Manawatu region (Pioneer Brand Products for 1994-95; Corson Grain Ltd 1994/95 Maize Planting Guide). CF1 is a hybrid developed by Crop and Food Research Ltd., Palmerston North from cold tolerant tropical highland germplasm and temperate adapted Iowa dent germplasm (A. Hardacre, personal communication).

Table 1. Hybrid characteristic.

HYBRIDS	Seed Source	CRM	Recommended plant population* (plants/ha)
Furio	Corson Seeds	95	100,000
CG900	Corson Seeds	105	100,000
Janna	Genetic Technologies	73	110,000
CF1	Crop & Food Research	98	-
P3585	Genetic Technologies	103	100,000
P3902	"	87	100,000
P3751	"	97	100,000

- recommended plant population by respective seed companies.

CRM -comparative relative maturity

3.3 EXPERIMENTAL DESIGN AND LAYOUT

A full factorial with 7 X 3 treatment combinations of 7 hybrids and 3 plant populations with four blocks arranged in randomized complete block design. (Table 2). A table of random numbers were used in assigning treatments in the experimental plots.

Each plot consisted of four 4 m rows, with 0.70 m spacing between rows. The outside two rows were used as border rows only.

3.4 HISTORY OF EXPERIMENTAL SITE AND CROP MANAGEMENT

The trial site had been previously cultivated for maize during the 1993/94 season. Prior to that, it was in long term pasture. The paddock was ploughed and cultivated prior to sowing. A soil test (15 cm cores) at the site indicated a pH of 5.7, Olsen P of 12, SO_4 values of 4.5 micrograms/gram (air-dry) and exchangeable K of 0.27 meq/100 g (air-dry).

Seed was sourced from Hodder and Tolley Ltd, Palmerston North (4 Pioneer hybrids), Corson Grain Ltd, Gisborne (2 hybrids) and Crop and Food Research (1 hybrid). Seed was treated with fungicide prior to sowing. After sowing insecticide (Thimet 20G) was applied to control insect pests.

Table 2. The 7 x 3 factorial treatment combinations of seven maize hybrids and three plant population levels.

Hybrids	Factorial Treatment Combinations					
	Plant Population Levels (P) ('000)					
	Trt. No.	75-P (1)	Trt No.	100-P (2)	Trt. No.	140-P (3)
Furio (A)	1	A1	8	A2	15	A3
CG900 (B)	2	B1	9	B2	16	B3
Janna (C)	3	C1	10	C2	17	C3
CF1 (D)	4	D1	11	D2	18	D3
P3585 (E)	5	E1	12	E2	19	E3
P3902 (F)	6	F1	13	F2	20	F3
P3751 (G)	7	G1	14	G2	21	G3

The seedbed was fertilized with 150 kg/ha of Diammonium Phosphate after the final cultivation, 9 days before sowing. Twenty five percent more seeds of the required quantity/ha were sown manually at 5 cm depth on 5th November 1994. Twenty seven days after emergence plants were thinned to achieve the required plant density for each of the treatments (*i.e* 75,000, 100,000 and 140,000 plants/ ha.).

Post-emergence herbicides (Gardoprim-500 FW and Tough) were applied to control broadleaf and grass weeds. (T. Lynch and K. Harrington, personal communication). Plots were sidedressed by hand 67 days after sowing with 100 kg N/ha as Ammonium Sulphate (21% N). Vertebrate pests (*i.e.* rabbit) were a problem in the early stages and were controlled by nighttime shooting.

The number of heat units in the experimental area were calculated using the following equation (Brooking and McPherson, 1989):

$$\text{Daily heat units} = \frac{(T_{\text{max}} + T_{\text{min}})}{2} - T_b$$

where: T_{max} = daily maximum temperature ($^{\circ}\text{C}$)
 T_{min} = daily minimum temperature ($^{\circ}\text{C}$)
 T_b = base temperature (6°C)

A base temperature of 6°C was chosen because it was able to account for 92% of the variation in crop duration from planting to harvesting of crops grown in Manawatu over five seasons (Brooking and McPherson, 1989).

3.5 CROP SAMPLING

Field observations were accompanied by sequential, destructive sampling of plants. Four plants in the inner two rows of each plot were harvested during the first three harvests. This was increased to six plants per plot at the final harvest. The initial harvest was made from one end with subsequent harvests alternating to the opposite end. For all harvests, the terminal plant in a row was not harvested.

The number of maize plants with emerge silks in the two inner rows of each plot were counted regularly to identify the date of 50% silking. Leaf number and plant height were recorded from two sampled plants in each plot once 50% silking occurred. Tagging of these sample plants to determine early leaf numbers as well as plant height commenced after the emergence of the sixth and seventh leaf of the maize plant.

Four harvests were taken from each plot beginning at 50% silking stage up to the final harvest stage when 30-35% whole crop dry matter was reached. Plants were pulled from the ground, labelled and transported to the laboratory for dissection and weighing. Table 3 lists the variables that were measured in the experiment.

(a) Plant height was measured from ground level to the point of attachment of the tassel peduncle at anthesis.

(b) Dry Weight - on arrival at the laboratory, plants were dissected into the following components: (i) leaves ; (ii) stems ; (iii) husks (sheath and cob); and (iv) grain. Fresh weights of these components were weighed and then subsampled for drying and

Table 3. Agronomic characteristics, crop DM yield and quality parameters measured in the study.

Harvest	Variables
Silking (1st Harvest)	Leaf Number
	Plant Height
	Yield and yield components
Harvest (2nd & 3rd)	Yield and yield components
Final Harvest	Yield and yield components
	Metabolizable Energy and Protein

calculation of dry matter %. Subsamples were dried in a forced draught oven for 48 hours at 85°C. Dry weight yields of plant components were calculated from fresh weights and the dry matter % of the component.

A subsample of the dried material from plant component from each plot in the 100,000 plants/ha plant population from the final harvest was ground through a 1mm sieve using a Cylotec 1093 Sample Mill, placed in an air tight container and submitted to the Animal Nutrition Laboratory, Massey University for analysis of digestibility and N%. Digestibility was determined using the "In Vitro" Digestibility Method. Kjeldahl Digestion with a Kjeltec Auto System was used to determine N%.

3.6 ANALYSIS OF DATA

Statistical analysis was carried out on computer with the SAS software system.

The statistical model used for the analysis was as follows:

$$X_{ijk} = U + A_i + B_j + AB_{ij} + R_k + E_{ijk}$$

where:

U = overall mean

A = treatment effects (Factor A)

B = treatment effects (Factor B)

AB = interaction effects

R = block effects

E = residual (unexplained variation)

i = 1 to 7

$$j = 1 \text{ to } 3$$

$$k = 1 \text{ to } 4$$

All effects in the model are assumed to be random. Results have been presented with F-test significances, least significant differences (LSD's) and coefficient of variation (CV's). Results with F-test significance greater than 5% have been reported as significantly different. Where interaction is significant, this has been reported. Where the F-test indicated significant differences among treatment means, LSDs (Prob. 0.05) have been calculated to discriminate between treatment means. The standard error has been indicated as vertical bars in Figures 1, 2, 4 and 5. Simple correlation analysis, a measure of the degree of association between variables was used to examine the relationship between variables.

CHAPTER IV

RESULTS AND DISCUSSION

CLIMATIC DATA, CROP YIELDS AND FEED QUALITY

4.1 INTRODUCTION

This chapter will summarise climatic data during the growing season, crop development, dry matter yields and feed quality in response to plant population and hybrid in maize. A brief discussion of each sub-topic is included.

4.2 CLIMATE

Daily maximum, minimum and average temperatures, heat units and rainfall over the total recording period are detailed in Appendix 1 and 2, respectively. Monthly mean temperature, heat units (HU) and rainfall during the maize growing season are given in Table 1.

Monthly mean temperature during the early season (November-December) was slightly lower than the 30-year average. Subsequent monthly mean temperatures (January onwards) were warmer than the 30-year average. These warmer temperatures coupled with adequate soil moisture provided favourable climate conditions during the reproductive period. Moisture stress was not apparent.

Cumulative heat units over the November 1994 to April 1995 maize growing season was greater than the 30-year mean. Total monthly HU accumulation varied

Table 1. Monthly mean temperature, heat units and rainfall data for the 1994/95 maize growing season at Palmerston North compared with the 30 year mean.

	Nov	Dec	Jan	Feb	Mar	Apr	Total
Mean Temp (°C)	14.0	15.9	17.7	18.9	17.1	15.9	
30-year ave	14.3	16.1	17.6	17.8	16.8	14.0	
Heat Units (6°C base)	214	306	363	360	343	298	1884
30-year ave	224	313	359	330	334	240	1800
Rainfall (mm)	180	46	54	58	142	104	584
30-year ave.	68	98	68	69	76	68	447

Source: AgResearch Grasslands, Palmerston North, New Zealand
 Lat: 40 23 S Long: 175 37E

during the growing season being less than average in November and December but greater in the mid to late months (January to April) compared to the 30-year mean.

Rainfall in November was 180 mm, 112 mm above the 30-year mean. A heavy downpour (159 mm) occurred 11 days after planting. This resulted in water ponding in the experimental area. Rotting of seeds, yellowing and death of emerging seedlings were observed in most plots. In contrast, warm and dry conditions prevailed during the summer months (December to February). The end of the season (March-April) was wet with rainfall exceeding the 30-year average (Table 1).

4.3 Development of the Maize Crop

4.3.1 Vegetative Period

The length of the period from sowing to 50% silking varied significantly ($P < 0.01$) between hybrids. CG900 and P3585 had longer vegetative periods than the other hybrids (Table 2). The medium maturing hybrids (CF1, P3751 and Furio) were three to five days earlier than the late maturing hybrids. As expected, the early maturing hybrids, P3902 and Janna were quickest to reach 50% silking.

The shortest duration to 50% silking occurred in the low plant population (92.14 days) significantly ($P < 0.05$) earlier than the medium and high plant populations (Table 3). There was no difference in the length of the vegetative period between the medium and high plant populations.

Table 2. The effect of hybrid on time and heat unit requirements from sowing to 50% silking and black layer formation.

Hybrids	Matu- rity	Days to 50% silking	Heat Units to 50% silking	Days to blacklayer formation	Heat Units to blacklayer formation
P3902	E	88.00	870.33	155.83	1,680.83
Janna	E	84.00	818.00	146.00	1,560.00
CF1	M	95.33	964.33	167.58	1,794.16
Furio	M	93.33	938.33	166.58	1,782.41
P3751	M	94.00	946.67	166.00	1,778.25
P3585	F	98.33	1,004.67	173.33	1,852.66
CG900	F	98.67	1,009.33	172.92	1,848.08
Mean		93.09	943.09	164.03	1,756.62
LSD (0.05)		1.62	21.74	1.23	11.44
CV (%)		0.98	1.30	0.92	0.79

E, M, F -early, medium and full hybrids, respectively.

Table 3. The effect of plant population on time and heat unit requirements from sowing to 50% silking and black layer formation.

Plant Population	Days to 50% silking	Heat Units to 50% silking	Days to blacklayer formation	Heat Units to blacklayer formation
75,000	92.14	923.42	163.25	1,748.39
100,000	93.29	938.42	164.43	1,760.21
140,000	93.86	946.00	164.43	1,761.28
Mean	93.09	952.61	164.04	1,756.62
LSD (0.05)	1.06	14.23	0.81	7.49

Previous research in New Zealand has shown that increasing plant population delays maturity, mainly by lengthening the vegetative period (Edmeades, 1972).

Analysis of variance of heat units (HU) from planting to 50% silking revealed significant hybrid ($P < 0.01$) and population ($P < 0.05$) effects. Mean HU accumulation between planting and silking was lowest in early hybrids (Janna and P3902) and increased steadily from medium (Furio, P3751 and CF1) to full season hybrids (P3585, CG900) (Table 2). Heat unit accumulation at 50% silking increased as the plant population increased from 75,000 to 100,000 plants/ha (Table 3). Although this trend continued at 140,000 plants/ha, the difference between 100,000 and 140,000 plants/ha was not significant.

4.3.2 Reproductive Period

Data on days and heat units accumulation from sowing to blacklayer formation are presented in Tables 2 and 3. Analysis of variance of these parameters revealed a highly significant hybrid, plant population and hybrid x plant population interaction effects.

Increased hybrid maturity and plant population resulted in an increase in the number of days and accumulated heat units required from planting to physiological maturity (black layer formation). Janna and P3902, both early maturing hybrids, required fewer days and heat units (Table 2). The three medium maturing hybrids

required the same time (166 days) which correspond to 1,785 heat units. The longest duration and heat unit accumulation was required by the full season hybrids.

Among the three plant population levels, differences in time and heat unit accumulation were only significant at 75,000 plants/ha (Table 3). The significant interaction between hybrid and plant population for heat unit accumulation resulted from increased HU accumulation as plant population was increased in Furio, CG900 and P3585 but no change in the other hybrids.

4.3.3 Plant Height

Analysis of variance of plant height reveals significant hybrid ($P < 0.01$) and plant population ($P < 0.05$) effects. In the present study, plant height appeared to be related to maturity ranking. The tallest hybrid (CG900) was significantly taller (1.83 m) than all other hybrids (Table 4). Plant height of medium maturing hybrids varied from 1.54 to 1.66 m. The lowest plant height was achieved by early maturing hybrids (Janna and P3902). A significant effect on plant height occurred as the plant population was increased to 140,000 plants/ha, (1.68 m) (Table 5). These results agree with those of Edmeades (1972) on the changes occurring in plants as plant population is increased. Duncan (1975) mentioned that maize plants in higher densities increase in height in response to mutual shading, although considerable variation was found in this characteristic. Earlier research reported by Dungan et. al. (1958) in Illinois showed little difference in total plant height as a result of varying plant populations.

Table 4. The effect of hybrid on plant height and leaf number.

Hybrids	Maturity Class	Plant Height (m)	Leaf No.
P3902	Early	1.52	15.96
Janna	Early	1.41	14.13
NZ81xMBS847	Medium	1.54	17.79
Furio	Medium	1.71	18.04
P3751	Medium	1.66	18.04
P3585	Full	1.74	18.25
CG900	Full	1.83	18.79
Mean		1.63	17.28
LSD (0.05)		0.08	0.49
CV (%)		6.02	3.48

Table 5. The effect of plant population on plant height and leaf number.

Plant Population (Plts/ha)	Plant Height (m)	Leaf Number
75,000	1.60	17.30
100,000	1.61	17.16
140,000	1.68	17.39
Mean	1.63	17.29
LSD (0.05)	0.05	ns

4.3.4 Leaf Number

Analysis of variance of leaf number at 50% silking showed significant hybrid effects ($P < 0.01$) only.

CG900 produced significantly more leaves (18.79) than all other hybrids (Table 4). The other late maturing hybrid P3585 and the three medium maturing hybrids (P3751, Furio and CF1) produced similar numbers of leaves. P3902 and Janna produced 15.95 and 14.12 leaves, respectively which were significantly lower than all other hybrids. Plant population did not affect leaf number (Table 5). A highly significant positive correlation ($r = 0.72$) was obtained between mean total leaf number and mean plant height, which is agreement with other workers (Hesketh et. al. 1969).

The results of the present study were similar to the reports of Chase and Nanda (1967) and Edmeades (1972a) who found that early maturing hybrids produce fewer leaves than the late maturing ones. This was further confirmed by the work of Warrington and Kanemasu (1983). Tollenaar (1992) reported that leaf number was significantly lower for plant densities above 12 plants/m² than for plant densities below 12 plants/m² with no significant hybrid x plant density interaction observed.

4.4 CROP YIELDS

4.4.1 50% Silking

Analysis of variance revealed significant hybrid and plant population effects at the 1% level of probability. The effect of hybrid and plant population on DM yields at 50% silking are presented in Tables 6 and 7, respectively.

At silking, Janna had the lowest total yield (5,696 kg DM/ha), significantly lower than all other hybrids. The highest yielding hybrid was CF1 (9,246 kg DM/ha) which exceeded Janna by 38% or 3,550 kg DM/ha. However there were no other significant differences between any other hybrids. Plant population had a significant effect on yield. The highest total yield/ha (10,362 kg DM/ha) was achieved at 140,000 plants/ha with 100,000 plants/ha intermediate and 75,000 plants/ha having the lowest yield (Table 7). Similar results were obtained by Thom (1977). Edmeades and Daynard (1979) reported shoot dry weight differences among plant populations at silking, as demonstrated in the current study and which increased with time. However, the shoot dry weight differences due to plant population in this study decreased at final harvest.

Table 6. The effect of hybrid on whole crop yield and percent of yield present as stem, leaf and husk at 50% silking.

Hybrids	Whole crop yield (kg DM/ha)	Percentage contribution to yield at 50% silking		
		Stem	Leaf	Husk
P3902	8,557	58.16	26.79	15.02
Janna	5,696	59.82	24.42	15.74
CF1	9,246	50.15	29.14	20.69
Furio	9,089	56.50	27.49	15.98
P3751	8,258	50.54	30.21	19.23
P3585	9,098	56.60	27.70	15.68
CG900	9,073	58.74	28.00	12.19
Mean	8,431	55.79	27.68	16.36
LSD (0.05)	1,408	2.27	2.00	2.75
CV (%)	20.45	4.98	8.86	20.61

DM -dry matter

Table 7. The effect of plant population on whole crop yield and percent of yield present as stem, leaf and husk at 50% silking.

Plant Population (Pl/ha)	Whole crop yield (kg DM/ha)	Percentage contribution to yield at 50% silking		
		Stem	Leaf	Husk
75,000	6,782	55.61	27.10	17.26
100,000	8,149	55.83	27.88	16.27
140,000	10,362	55.92	28.05	15.56
Mean	8,431	55.79	27.68	16.36
LSD (0.05)	921	ns	ns	ns

DM -dry matter

4.4.2 Final Total Dry Matter (DM) Yields

The effect of hybrid and plant population on final yield are shown in Tables 8 and 9, respectively. Analysis of variance revealed significant hybrid ($P<0.01$) and plant population ($P<0.01$) effects with no significant hybrid and plant population interactions.

At final harvest, CF1 achieved the highest yield (20,046 kg DM/ha) significantly greater than Janna, Furio, P3751 and CG900 (Table 8 and Fig. 1). Janna remained the bottom hybrid, yielding (15,775 kg DM/ha).

Averaged across hybrids, increasing plant population significantly improved total crop dry matter yield by 11.89% between 75,000 and 100,000 plants/ha, with a non significant increase of 4.73% between 100,000 and 140,000 plants/ha (Table 9 and Fig. 2). The small non-significant increase in yield occurring when plant population increased from 100,000 to 140,000 plants/ha confirmed the earlier work of Phipps (1975) and Bunting (1971) which suggested plant population of between 100,000 and 150,000 plants/ha as being the optimum for maize silage production. Thom et. al.(1981) showed that under New Zealand conditions a significant increase in total dry matter yield per hectare at the 'hard dent' stage (30-35% DM) was possible by increasing the established population up to 166,000 plants/ha.

Table 8. The effect of hybrid on whole crop yield; crop DM%; percent yield present as stem, leaf, husk and grain, at final harvest.

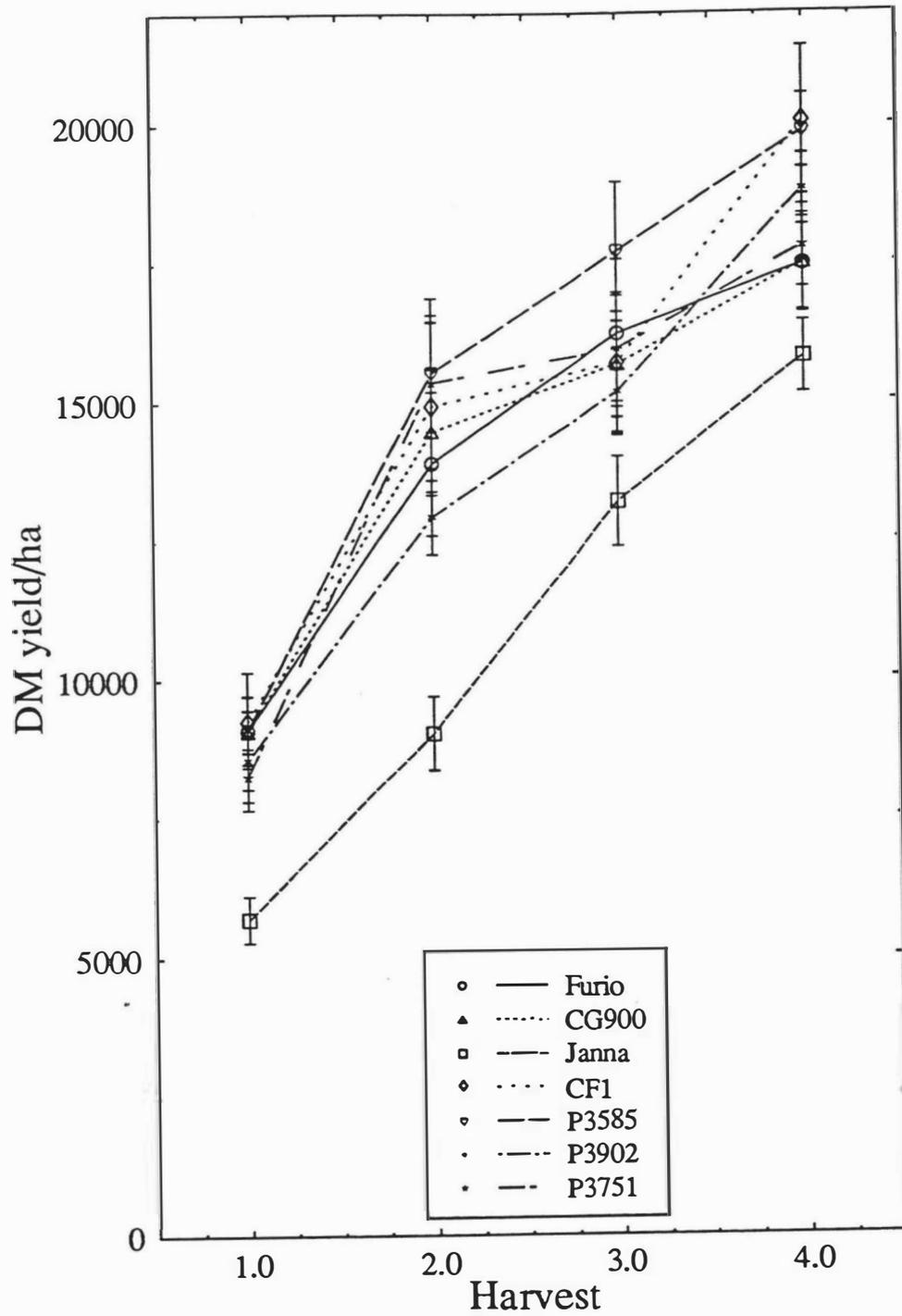
Hybrids	Whole crop yield (kg DM/ha)	Whole crop DM %	Percentage contribution to final yield			
			Stem	Leaf	Husk	Grain
P3902	18,807	35.80	23.34	10.68	19.37	46.58
Janna	15,776	37.88	21.60	8.03	19.61	50.72
CF1	20,046	30.21	28.21	12.64	18.90	41.23
Furio	17,449	36.07	25.20	11.31	19.54	43.92
P3751	17,776	35.02	24.45	11.78	15.74	47.99
P3585	19,864	35.02	25.81	11.84	17.27	45.05
CG900	17,466	33.17	28.97	12.30	17.24	41.47
Mean	18,169	34.74	25.37	11.23	18.24	45.28
LSD (0.05)	2,177	1.72	1.73	0.62	1.14	2.03
CV (%)	14.67	6.09	8.36	6.82	7.66	5.5

DM -dry matter

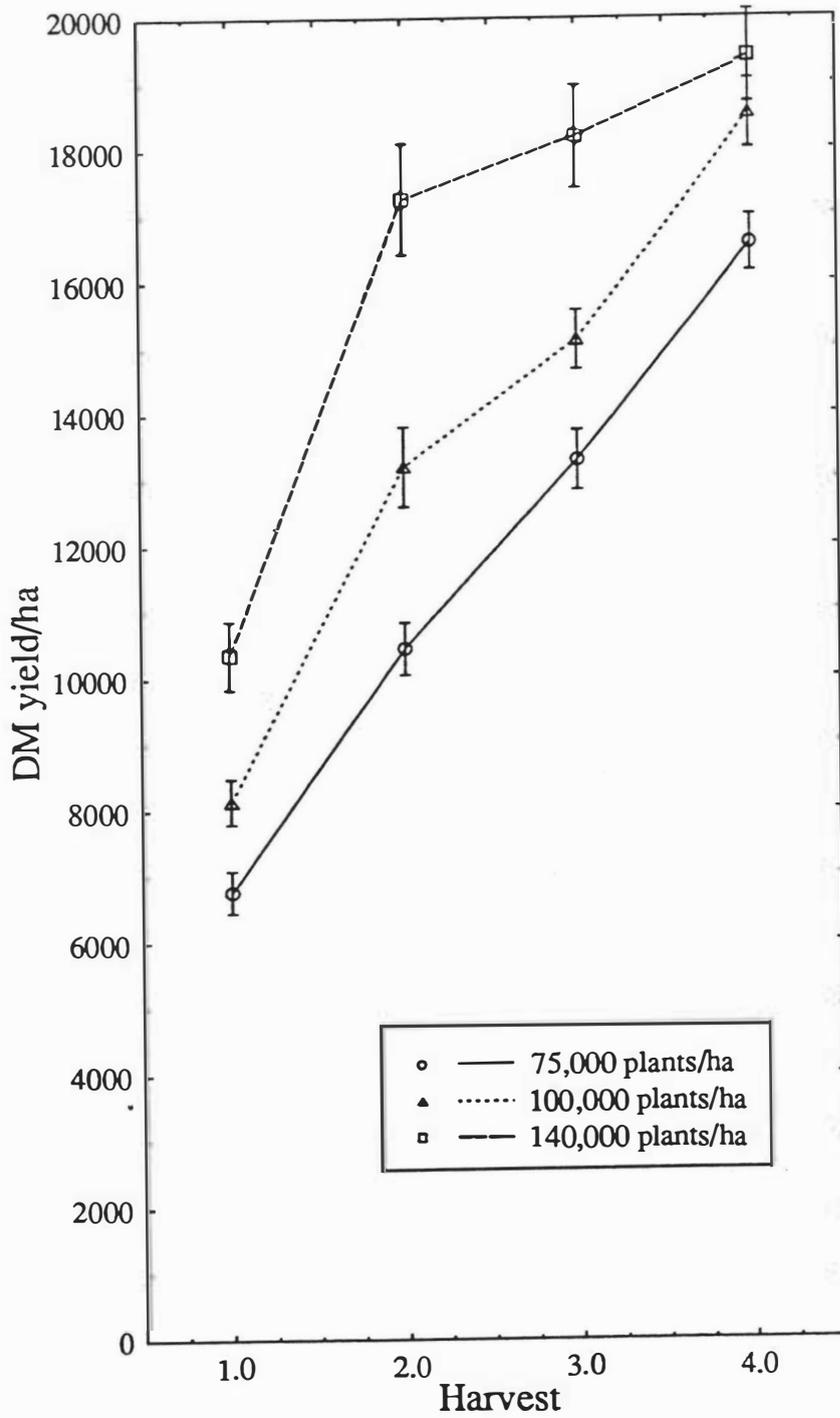
Table 9. The effect of plant population on whole crop yield; crop DM%; % of yield present as stem, leaf, husk and grain at final harvest.

Plant Population (Plts/ha)	Whole crop yield (kg DM/ha)	Whole crop DM %	Percentage contribution to final yield			
			Stem	Leaf	Husk	Grain
75,000	16,557	35.00	25.59	10.41	18.89	45.08
100,000	18,527	34.53	25.22	11.19	18.45	45.56
140,000	19,404	34.68	25.30	12.08	17.38	45.20
Mean	18,162	34.74	25.37	11.23	18.24	45.28
LSD (0.05)	1,425	ns	ns	0.41	0.74	ns

Fig. 1. The effect of hybrid on dry matter accumulation between 50% silking and final harvest.



2. The effect of plant population on accumulation of dry matter between 50% silking and final harvest.



4.4.3 Whole Plant Dry Matter Content (%) at Final Harvest

Differences in whole plant dry matter % were found to be significant among hybrids ($P < 0.01$) and non-significant among plant populations. Janna had the highest average whole plant DM percentage of 37.88%, significantly greater than all other hybrids (Table 9). P3751, P3585, P3902 and Furio had similar DM percentage (35-36%). The lowest whole plant DM percentage of 30.21% was recorded in CF1, 7.8 % less than Janna. Although the plant population effect was not significant, it was observed that the whole plant DM percentage tended to decrease as the plant population increased (Table 9).

Results from the present study indicate that whole plant DM percentage was within the acceptable range for harvesting silage (Vetter and Von Glan 1978). Lusk (1978) reported that silage preserved between 30 and 40% DM percentage provides acceptable fermentation, preservation and animal performance. Recent research (Wiersma et. al. 1993) has confirmed the 30 to 40% whole plant DM % as optimum for silage. Over this range, grain is between the 1/2 and 3/4 milkline stages. Maximum whole plant yield was reached by 1/2 milkline while grain yield reached maximum yield at 3/4 milkline.

4.5 DRY MATTER (DM) PARTITIONING

4.5.1 50 % Silking

Analysis of variance of the % contribution of stem, leaf and husk to total yield at 50% silking revealed a significant hybrid effect ($P < 0.01$) and non-significant plant population effect. A significant ($P < 0.01$) hybrid x plant population interaction was observed for husk percentage however, this interaction was an exception and not considered to be important.

Stems contributed the greatest proportion of total yield at silking (Table 6), ranging from 59.8% of the total DM (Janna) down to 50.2% (CF1). The stem % of P3571 and CF1 were significantly lower than all other hybrids.

P3751 had the highest percentage of the total yield as leaf (30.2%), being approximately 6% higher than Janna, the hybrid with the lowest % leaf. There was no difference between CF1 and P3751 however Janna was significantly lower than all other hybrids. The proportion of leaf in remaining hybrids did not vary substantially.

The husk percentage of total yield varied markedly among hybrids with values ranging from 12.2% (CG900) to 20.7% (CF1). The interaction between hybrid and plant population for husk % was due to declining husks % in Janna, CF1, P3585 and CG900 with increasing plant population. However, the response in the remaining hybrids was

inconsistent, occurring from 100,000 to 140,000 plants/ha only.

Plant population had no effect on DM partitioning at 50% silking (Table 7). Mean stem, leaf and husk percentage of total DM contributed 55.8, 27.7 and 16.4 %, respectively.

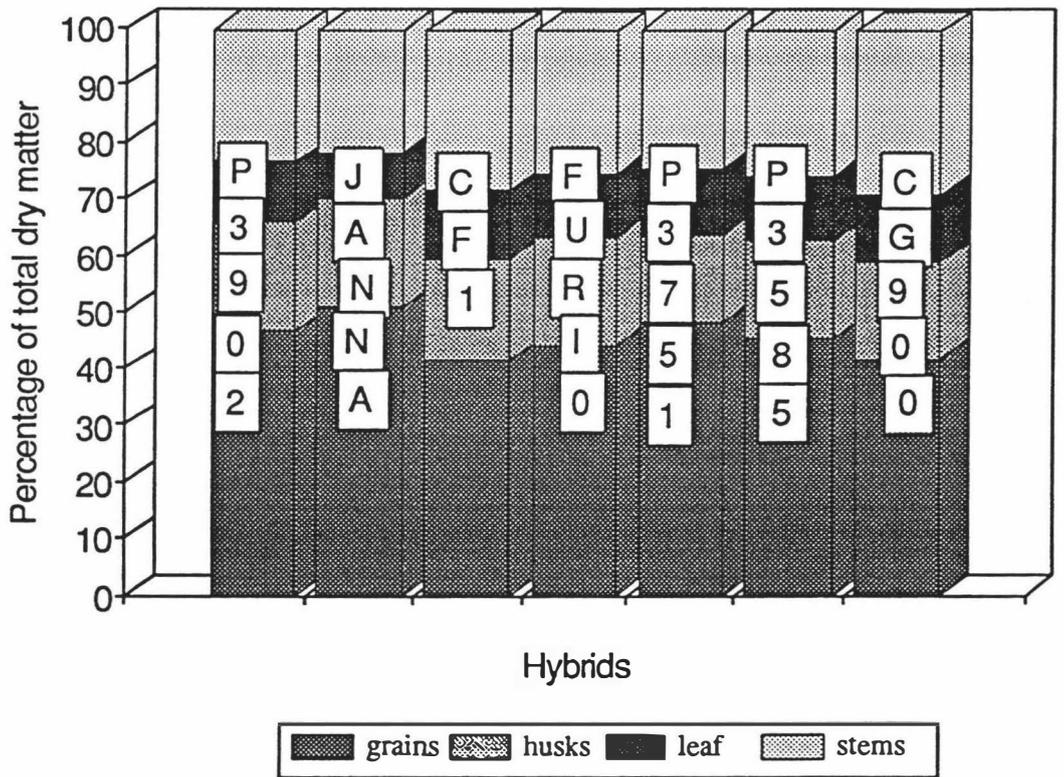
4.5.2 Final Harvest

Dry matter partitioning at final harvest is important because of the effect it may have on feed value in particular. The grain portion (45.3%, mean) is of importance because it is the major determinant of energy value of maize silage. An increase in this component may lead to improved nutritive value. However, the stover components, namely; stem (25.4%), husk (18.2%) and leaf (11.2%) contribute 50% of crop DM, thus are also very important in maize silage production.

Analysis of variance of DM partitioning at final harvest showed significant hybrid ($P < 0.01$) effects for % stem, leaf, husk and grain. Plant population effects were significant ($P < 0.01$) for % leaf and husks only.

At final harvest, grain provided the greatest contribution to total yield (Fig. 3). Janna exhibited the highest grain % (50.72%) of the total yield, significantly greater than all other hybrids. (Table 8). CG900 (41.47%) and CF1 (41.23%) produced the lowest grain %, significantly less than all other hybrids.

Fig 3. Dry matter partitioning in maize hybrids at final harvest.



A large reduction in stem % of total yield occurred between silking and final harvest in all hybrids (Fig. 4). At silking stem % accounted the highest proportion averaging 55.8% across hybrids. This decline continually as the season progresses and at final harvest, its proportion was reduced to less than half that at 50% silking.

Stem % of CG900 (28.79%) and CF1 (28.21%) were significantly greater than P3585, Furio and P3751 (Table 8). P3902 differed significantly from P3585 and Furio. Janna had the lowest % stem (21.60%) significantly lower than all other hybrids.

Similarly, leaf % of total yield also decreased between 50% silking and final harvest (Fig. 5). Leaf % at 50% silking averaged at 27.7%. This decreased steadily reaching 11% at final harvest.

At final harvest the leaf % of Janna (8.03) was significantly lower than all other hybrids, while P3902 was lower than all hybrids except Janna. CF1 had the highest % leaf (12.64%) significantly greater than all other hybrids except CG900.

There was relatively little variation in % husk between hybrids . Janna had the highest husk %(19.61%) at final harvest, significantly greater than P3585 and CG900. P3751 had the lowest husk % significantly less than all other hybrids (Table 8).

The effect of plant population on DM distribution at final harvest was less than that of hybrid (Table 9). Only leaf and husk % were significantly ($P < 0.01$) affected. The % leaf declined as plant population declined with each population level being

Fig. 4. The effect of hybrid on percent stem between 50% silking and final harvest.

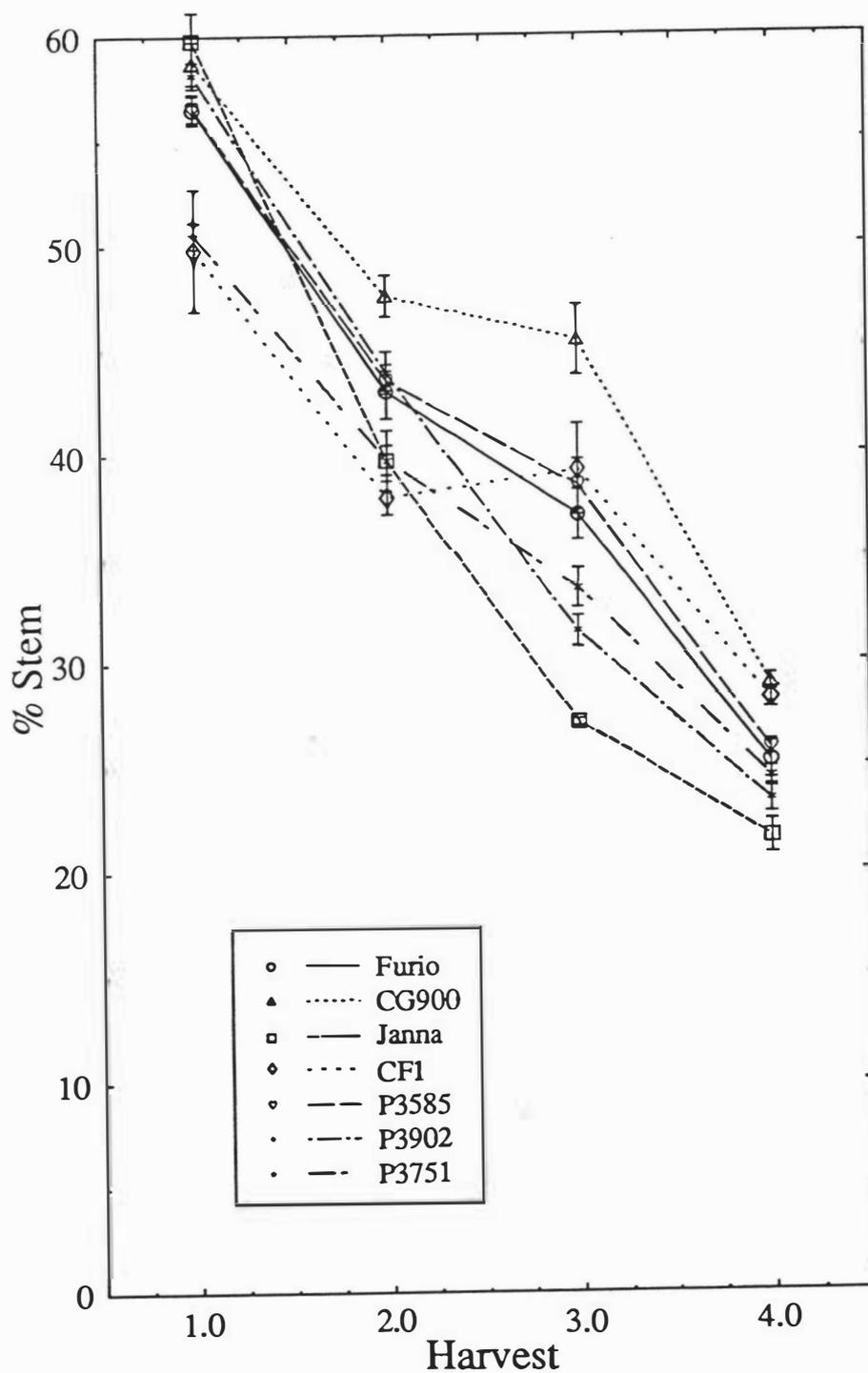
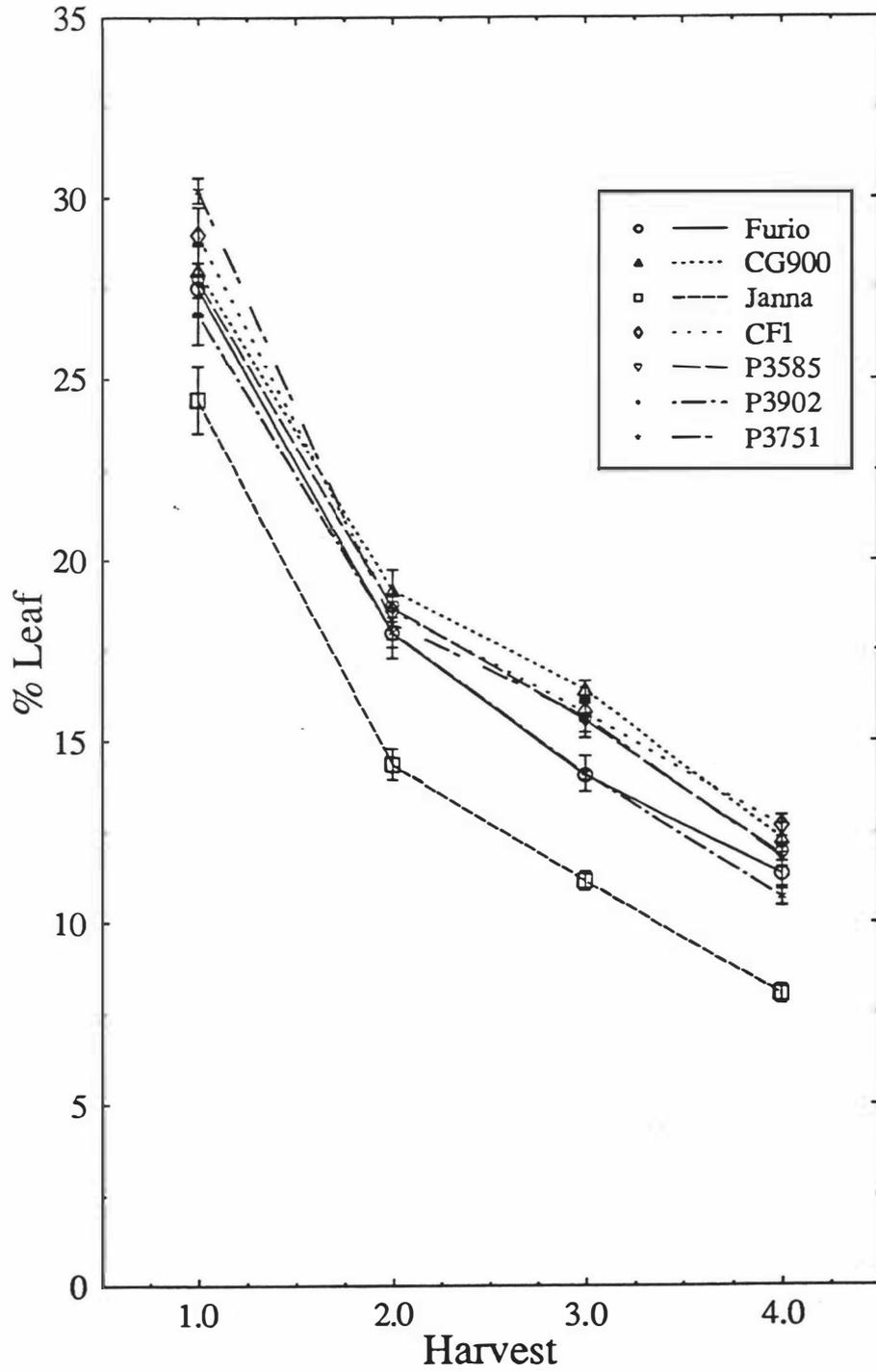


Fig. 5. The effect of hybrid on percent leaf between 50% silking and final harvest.



significantly different from the others. In contrast, husk % decreased with increasing plant population.

The DM distribution at final harvest is similar in trend to earlier research. Menalda and Kerr (1973) concluded that important changes occur in the proportions of leaves, stalks, grain and non-grain parts of the ear, and dry matter content as the crop matures. These changes are influenced to some extent by hybrid, planting date, plant population and by other environmental factors. In a study on planting density and yield partitioning of two maize hybrids in Nigeria, Lucas and Remison (1984) found that there was no effect of planting density on the partitioning of yield between reproductive and vegetative parts.

From the pattern of yield partitioning found in this study, there is an indication of remobilization of assimilates from the stems and leaves to the grains. This remobilization is suggested by the considerable loss in stem weights towards the end of the growing season, which could not be all attributed to losses through respiration. This period coincided with the time of high dry matter accumulation in the grains. The results of the present study contradicts a previous report on old maize hybrids by Van Eijnatten (1963), who found no evidence of any remobilization to the grain in tropical maize hybrids. Later studies have shown however, evidence of remobilization of stem assimilates to the grain both in temperate and tropical maize hybrids (Daynard et. al. 1969; Adelana and Milbourn, 1972; Wilson and Allison, 1978; Lucas and Remison, 1984).

4.6. FEED QUALITY

4.6.1 Metabolizable Energy (ME) Contents

Analysis of variance on the whole crop ME values revealed significant ($P < .05$) differences among hybrids (Table 10). Whole crop ME value was highest in CF1 (11.32 MJME/kg DM), being significantly greater than all other hybrids tested in the present study (Table 10). There were no other differences among the hybrids.

The whole crop ME values obtained in the present study are comparable to the maize silage ME values reported in Australia, England, Holland and United States having ME values of 10.2, 10.8, 10.9 and 11.2 MJ/kg DM, respectively (Moran, 1984).

Total ME yield/ha was calculated for each hybrid as the product of total DM yield/ha and ME content. Analysis of ME yield/ha revealed no significant differences among hybrids (Table 10). However, CF1 outperformed other hybrids producing 225,984 MJME/ha, 7% more than the next highest hybrid, Furio. Janna produced 166,232 MJME/ha, the lowest among the hybrids tested.

Analysis of variance of the ME content of the grain revealed significant ($P < .05$) differences among hybrids. The highest ME value in the grain was 12.88 MJME/kg DM obtained from CF1 (Table 10). P3902 and P3585 contained significantly lower ME values than all other hybrids. There were no other differences among hybrids.

Table 10. The variation in metabolizable energy content among hybrids planted at 100,000 plants per hectare.

Hybrids	Metabolizable Energy (MJME/kgDM)					ME Yield Per Ha.
	Total	Grain	Leaf	Husks	Stems	
P3902	10.46	12.62	9.47	9.62	7.15	200706
Janna	10.73	12.72	9.49	9.56	7.63	166232
CF1	11.32	12.88	9.79	11.24	8.65	225,984
Furio	10.72	12.83	9.07	10.18	8.09	209,052
P3751	10.72	12.68	9.50	10.04	7.87	197662
P3585	10.28	12.61	9.40	10.43	7.39	202141
CG900	10.51	12.74	8.79	10.33	8.16	187853
Mean	10.68	12.73	9.36	10.20	7.85	198,518
LSD (0.05)	0.55	0.17	0.46	0.51	0.70	ns
CV (%)	3.46	0.88	3.30	3.38	5.96	14.49

Highly significant differences among hybrids were observed in the ME contents of the husks (Table 10), with CF1 (11.24 MJME/kg DM) having a significantly higher ME value than all other hybrids. Differences in the ME contents of the husks of P3585, CG900, Furio and P3751 were negligible. The two early maturing hybrids (P3902 and Janna) contained the lowest ME values being significantly lower than all hybrids except P3751.

The ME contents of the leaf differed significantly ($P < 0.01$) among hybrids (Table 10), with CF1 having the highest (9.79 MJME/kg DM) ME value, though not significantly higher than P3902, Janna, P3751 and P3585. CG900 was lower than all other hybrids except Furio.

Significant differences in ME values of the stems were also found. Again, CF1 excelled, containing the highest ME content (8.65 MJME/kg DM) (Table 10), significantly greater than P3902, Janna, P3751 and P3585. There were no other differences among the other hybrids.

4.6.2 Nitrogen %

No significant differences were revealed by analysis of variance of the overall N % (Table 11). Overall N % was highest (1.16%) in Janna, (which also had the lowest yield) and lowest in Furio (1.05%)(Table 8).

Table 11. The variation in overall N % and its corresponding percentage in plant components, NHI and N yield among maize hybrids planted at 100,000 plants per hectare.

Hybrids	Overall N %	N% of Components				NHI	N Yield (kg/ha)
		Grain	Leaf	Husk	Stem		
P3902	1.07	1.45	2.18	0.40	0.30	0.64	203.55
Janna	1.16	1.65	2.11	0.33	0.35	0.72	180.16
CF1	1.16	1.74	2.21	0.58	0.37	0.57	220.43
Furio	1.05	1.41	2.22	0.40	0.37	0.60	204.38
P3751	1.09	1.39	2.12	0.46	0.38	0.62	201.87
P3585	1.08	1.48	2.04	0.42	0.34	0.63	206.97
CG900	1.07	1.49	2.33	0.51	0.29	0.57	192.23
Mean	1.10	1.51	2.17	0.44	0.34	0.62	201.37
LSD (0.05)	ns	0.14	ns	0.09	ns	0.04	ns
CV (%)	11.61	6.29	8.63	13.58	15.13	5.20	15.89

NHI - Nitrogen harvest index

The total N % of the maize silage hybrids obtained in this study is lower than those reported by other researchers in temperate environments (Linton, 1975; McAllan and Phipps, 1977; Iremiren and Milbourn, 1978; Wilkinson, 1978; Fairey, 1982; Wilkinson, 1985). Moran (1984) in his three year study on maize silage in Australia mentioned a range of total N % from 1.28 to 1.80%. The range in total N % obtained in this study is comparable to the range of total N % of maize silage hybrids grown in a tropical climate (0.8-1.3%) (Wilkinson, 1985). Crop yield stage of maturity at harvest and the level of fertilizer-N applied to the crop can all influence N% (Fairey, 1982; Wilkinson, 1985).

Total N yield/ha was computed for each hybrid as the product of total DM yield/ha and total N %. Analysis of total N yield/ha indicated no significant differences among hybrids (Table 11). CF1 yielded the highest (220.43 kg/ha) total N yield. Total N yield of other hybrids ranged from 180.16 kg/ha (Janna) to 206.97 kg/ha (P3585).

The N % in the grain component showed significant ($P < 0.01$) differences among hybrids (Table 11). N % in the grain of CF1 (1.74%) and Janna (1.65%) were significantly higher than all other hybrids, whose values ranged from 1.39 to 1.49%.

N % in the leaf did not differ among hybrids (Table 11), values ranging from 2.33% (CG900) to 2.04% (P3585).

Highly significant differences occurred in husk N % (Table 11). CF1 contained the highest (0.58%) N % but was not different from CG900. The other hybrids had N

% values ranging from 0.46 to .40%. Janna contained significantly less (0.33%) N than CF1, P3751, and CG900.

Differences in N% of the stems were small and non significant (Table 11).

Nitrogen harvest index (NHI) was calculated (ratio of N in the grain:total crop N) for each plot. It is a measure of remobilisation efficiency during crop maturation. There were considerable variation in NHI due to hybrid (Table 11). Janna had a significantly higher (0.72) NHI than all other hybrids. P3902, P3585, P3751 and Furio were intermediate with CF1 and CG900 being lowest (0.57) than all other hybrids. Nitrogen harvest index was correlated with % grain of total DM to examine relationship between distribution of DM and N at harvest. Nitrogen harvest index was highly correlated ($r=0.82$) with % grain suggesting that remobilisation of DM and N during crop maturation are related.

Correlation analysis was also used to examine the relationship between DM yield and yield components, and ME value and ME components.

Final yield was not correlated with %grain, % stem, %leaf or % husk indicating that yield is not dependent on DM partitioning (Table 12). It was not also correlated to ME value and ME components but was strongly, positively correlated ($r=0.97$) to MEY indicating that final yield is much important than ME value in determining MEY.

Table 12. Simple correlation coefficients for final yield, % yield in grain, stem, leaf and husk, total metabolisable energy and metabolisable energy of different plant fractions.

	FY	% Grain	% Stem	% Leaf	% Husk	TME	MEG	MEL	MEH	MES	MEY
FY		-0.128	0.078	0.089	0.099	-0.020	-0.060	-0.093	0.211	-0.111	0.97**
% Grain			-0.80**	-0.63**	-0.091	-0.133	-0.45*	0.164	-0.61**	-0.59**	-0.150
%Stem				0.74**	-0.274	0.323	0.39*	-0.121	0.66**	0.53**	0.149
%Leaf					-0.326	0.357	0.22	0.083	0.56**	0.45*	0.169
%Husk						0.320	0.213	0.037	0.054	0.103	0.168
TME							0.48**	0.40*	0.54**	0.51**	0.209
MEG								0.170	0.40*	0.49**	0.050
MEL									0.127	-0.416	-0.001
MEH										0.369	0.327
MES											0.004
MEY											

*, ** - significant at 5% and 1% level of probability, respectively.

FY - Final yield

TME - Total metabolizable energy content

MEG, MEL, MES, MEH - Metabolizable energy content of the grain, leaf, stem and husk

MEY - Metabolizable energy yield

Percent grain was strongly, negatively correlated with % stem ($r=-0.80$) and % leaf ($r=-0.63$)(Table 12). Percent stem was strongly correlated to % leaf ($r=0.74$). This suggests that both leaf and stem are important sources of DM during grain development.

Total metabolizable energy (TME) was correlated with its ME components in the grain ($r=0.48$), leaf (0.40), husk (0.54) and stem (0.51)(Table 12) indicating that all these components are important in the determination of total crop ME value.

Final yield was not significantly correlated to % N total crop indicating that high DM yield did not necessarily result in N dilution, allowing the possibility of both high yield and high N% possible (Table 13).

Nitrogen % of total DM was strongly correlated ($r=0.59$) to N % in the grain and moderately correlated to N % in the stem ($r=0.42$) and N % in the leaf ($r=0.43$). Grain contributed the greatest proportion to final yield. While leaf was a minor component of final yield, N % was higher than all other components (Table 11).

Table 13. Simple correlation coefficients for final yield, nitrogen %, yield components, total nitrogen %, nitrogen harvest index, nitrogen yield, grain yield and % grain.

	FY	N% Grain	N% Leaf	N% Husk	N% Stems	%N TDM	NHI	N Yield (kg/ha)	Grain Yield (kg/ha)	% Grain
FY		-0.034	-0.117	0.088	0.054	-0.339	-0.112	0.67**	0.86**	-0.12
N% Grain			0.117	0.44*	0.27	0.59**	0.097	0.33	-0.16	-0.23
N% Leaf				0.21	0.28	0.43*	-0.46*	0.21	-0.19	-0.24
N% Husk					0.361	0.304	-0.67**	0.25	-0.25	-0.71**
N% Stems						0.42*	-0.204	0.33	0.08	-0.0009
N% TDM							0.051	0.44*	-0.21	0.11
NHI								-0.04	0.28	0.82**
N Yield									0.68**	0.025
Grain Yield										0.38*
%Grain										

*, ** - significant at 5% and 1% level of probability, respectively.

FY - Final yield

CHAPTER V

DISCUSSION

5.1 CLIMATE

The 1994/95 growing season was generally favourable for maize growth averaging 0.6°C warmer over the growing season compared to the long term average. December was close to average with January and February being warmer. There was no apparent moisture stress. Rainfall was variable through the growing season with November, March and April being well above the normal average. In contrast the December to February months had below the normal precipitation. Total heat unit accumulation during the growing season was above average.

5.2 CROP DEVELOPMENT

Plants at the lowest plant density (75,000 plants/ha) were reached 50% silking and blacklayer formation earlier than plants at the medium (100,000 plants/ha) and high (140,000 plants/ha) plant populations. The duration of crop development was least for early hybrids followed by medium hybrids and longest for full season hybrids, in line with their relative maturity ratings. The rate of crop development in the current study was enhanced due to warmer than average temperatures (Table 1). Delayed crop development may result from lower than average temperatures (Wilson et. al. 1994). However, Menalda and Kerr (1973) found that crop development may also be affected by moisture. The occurrence of excess rainfall in the pre and early emergence stage of

the crop resulted to rotting of seeds and death of emerging seedlings. However, subsequent shoot growth was not adversely affected. This was evident from the rapid recovery of the maize seedlings, the result of favourable temperatures as the season progressed. During establishment scattered water ponding occurred after heavy rain however quickly receded due to the free draining nature of the soil (fine sandy loam). This paved the way for the restoration of gas exchange between soil and atmosphere. Maize seminal roots may survive for up to 70 hours under anaerobic conditions (Sachs et. al. 1980 cited by Jackson and Drew, 1984).

Plant height was reduced at low plant populations only. Wallace and Davies (1976) observed that differences in plant height at increasing densities were relatively small. Tetio-Kagho and Gardner (1988) found that plant height increased to a maximum and then decreased parabolically with increasing plant population. Plant height was greatest at 6 to 10 plants m^{-2} . The limitations of assimilate and perhaps mineral and water was probably associated with the decrease of plant height at highest plant population (Tetio-Kagho and Gardner, 1988). Plant height of the hybrids in the current study ranged from 1.41 m (early hybrids) to 1.83 m (late hybrids) while leaf number ranged from 14 to 18 for early and late hybrids, respectively. It appears that both plant height and leaf number are related to maturity. Warrington and Kanemasu (1983c) found that hybrid differences in leaf number were consistent with their maturity ranking.

5.3 DRY MATTER YIELDS

Dry matter yields increased (16,557, 18,527 19,404 kg/ha) as the plant population was increased from 75,000, 100,000 to 140,000 plants/ha, however yields at the high plant population (140,000 plants/ha) were not significantly different from the medium plant population (100,000 plants/ha). This indicates that within this range, the plant population/yield relationship is probably asymptotic (Bryant and Blaser, 1968).

These yields are similar to those reported from previous New Zealand studies (Buxton, 1974). Edmeades (1972) concluded that sowing rates for late maturing hybrids should not exceed 50,000 plants/acre (123,500 plants/ha) and for early hybrids should not exceed 70,000 plants/acre (172,000 plants/ha) except under highly fertile and well-watered condition. Buxton (1975) and Smith (1982) mentioned that maize sown for silage in New Zealand should be sown at a plant population of 100,000 plants/ha. Thom et. al. (1981) found that at the hard dent growth stage, maize planted at 181,000 seeds/ha outyielded that sown at 85,000 seeds/ha by approximately 13%. No further yield increment was obtained from maize planting at 362,000 seeds/ha. The present study confirms the existing recommended plant population of 100,000 plants/ha for commercial maize hybrids in New Zealand. At this plant population, an additional income of more than NZ\$200.00/ha (silage price at 14c/kg DM) will be generated by the grower after deducting the seed cost (NZ\$247/100,000 seeds/ha).

Whole crop DM yield at final harvest differed significantly among hybrids. Variation in DM yields among hybrids of varying maturities is typical (Graybill et. al. 1991). Cumberland et. al. (1971) reported that total DM yield closely reflected the ranking of hybrids on the basis of grain yield. The hybrids used in their study were bred for maize grain production. The yield of P3902 in this study was similar to yields reported by Wilson et. al. (1994) for P3902 from early November sowing at Lincoln during the 1989/90 and 1990/91 seasons. Mean temperatures for Lincoln over the 1989/90 season were similar to the current study, being long enough for P3902, an early hybrid to expressed its maximum DM yield potential. However, the DM yield of P3585, a full season hybrid was higher in the present study compared to the yield achieved at Lincoln. At Lincoln, this hybrid was affected by frost prior to maturity.

The results of this study suggest that CF1 is a promising hybrid on the basis of DM yield production. P3902 appears to be similar to P3585 and better than Furio, P3751 and CG900. Lowest DM yield was achieved by Janna.

5.4 WHOLE PLANT DRY MATTER PERCENTAGE

The plant population levels in the present study did not influence DM % at harvest. This agrees with the findings of White (1976), Thom et. al. (1981) and Fairey (1982). The DM % at final harvest (30-38%) fell within the ideal range for maximum silage quality (Wiersma et. al., 1993; Vetter von Glan, 1978; Lusk, 1978). Obtaining the optimum DM% (30-35%) is important for the ensiling process. Low DM silages are susceptible to significant seepage losses under the high compactive pressures developed

in tower silos (Gordon, 1967). Most researchers agree that seepage losses are eliminated once plant DM % reaches 30-35% (Zimmer, 1971; Daynard et. al., 1978). Thus maize genotypes selected for maize silage production should be capable of reaching at least this DM% at the time of harvest. In addition to the importance of DM % on the ensiling process, many researchers have shown that animal DM intake is reduced when animals are fed low DM maize silage (Huber et. al. 1965; Owen, 1967; Waldern 1972). Other researchers have been unable to detect this same decrease in DM intake (Huber et. al. 1968; Goering et. al. 1969).

5.5 DRY MATTER PARTITIONING

In the current study, DM partitioning among yield components was not influenced by plant population at 50% silking or at final harvest except in leaf and husk proportions. This suggest that increased competition from higher plant populations did not have an adverse effect on reproductive growth in this trial. Allison (1969) reported that the distribution of DM in maize changed with population. In his experiment the % of the total DM in the leaves increased with population, e.g. at 10 weeks from sowing, 26% and 34% of the total DM was in the leaf laminae, with populations at 23,000 and 73,800 plants/ha, respectively. At higher plant populations, the grain received a greater fraction of the increment in DM after flowering. The increased proportion of DM that moved to the grain when population increased was evidently at the expense of stem, husks and core. MacAllan and Phipps (1977) found that the proportion of leaf and stem decreased at low (50,000 plants/ha) and high (150,000 plants/ha) density but a greater reduction in both components was observed in the low density. This contrasts with the

results of this study which found that % grain was not affected by plant population. It is worthwhile mentioning that final harvest in the present study was measured when the whole crop DM % was in the 30-35% range and not at physiological (maximum grain yield) maturity as was the case with McAllan and Phipps (1977). At this whole crop DM %, maximum whole crop yield (grain and stover components) is attained and nutritive value is maximum (Wiersma et. al. 1993). The pattern of DM partitioning among hybrids in the present study agrees with previous research (Menalda and Kerr, 1973; Tollenaar, 1977; Thom et. al. 1981). For example, the stem proportion was greatest at 50% silking in all hybrids, but was overtaken by the grain component which provided the greatest contribution to total DM at final harvest. The leaf proportion was also reduced while the husks component showed an increased in its contribution at final harvest. Examination of the % grain in final yield in the present study (Table 8) indicates that early hybrids had a greater proportion of grain compared to the mid and full season hybrids. This is in agreement with many other workers (Genter and Camper, 1973; Hunt et. al. 1992). This seem to indicate that early hybrids took advantage of the growing season during the grain filling period, partitioning more dry matter into the grain which results in higher harvest index (Deloughery and Crookston, 1979). Further, the response of the early hybrids can probably be attributed to more efficient use of sunlight with no apparent moisture stress in the field during long daylight hours of summer months (Knapp and Shaw Reid, 1981), as was the case in the current study.

In most countries, the approach to selecting a high yielding hybrid for maize silage production is to suggest that farmers choose the highest yielding grain hybrid (Pollmer, 1980; Vattikonda and Hunter, 1983; Hunter, 1986). This approach is probably

based on the belief that highest-grain yielding hybrids were also high silage yielding hybrids and may simply reflect the fact that approximately half the total silage yield is grain (Nevens and Dungan, 1942 as cited by Hunter, 1978). However this study found no relationship ($r=-0.128$) between the proportion of grain in hybrids and final yield. This suggests that it is important to consider the grain and stover portions in order to obtain maximum yield.

The NHI obtained among hybrids in the current study indicates the efficiency of N translocation to the grain. The present study suggests that early hybrids are more efficient at translocating N to the grain than are late hybrids. This agrees with the earlier reports that NHI is influenced by hybrid indicating genotype differences in the accumulation of large quantity of N or using N more efficiently through translocation from various plant parts (Beauchamp et. al., 1976; Tsai et. al. 1992; Feil et. al., 1993).

The relative grain yield of maize (the yield expressed as a percentage of the maximum yield) is related to the concentration of N in grain at harvest (Steele, 1981). Maximum relative yield is achieved when N content is about 1.5%. Relative yield declines if grain N % is below or above this level. The N % of grain achieved in this study ranged from 1.39% to 1.74%. This indicates that relative yields in the current study fell in the 95% to 100% range, thus N was not limiting yield. Earlier reports indicated that relative yield-percent N relationships for grain covering 15 hybrids and a range of locations and plant populations showed that % N associated with maximum grain yield ranged from 1.38 to 1.77 % (Pierre et al. 1977).

5.6 FORAGE QUALITY

Metabolisable energy differences among DM yield components reflected the whole plant ME content. Among the hybrids tested in the current study, CF1 had the highest ME content in the grain, husk, leaf and stem components giving it the highest overall ME content (Table 10). The non-significant variation in whole crop digestibility of P3902, P3751 and P3585 in this study confirmed the similar silage digestibility ranking given by the Genetic Technologies Ltd (1995/96 Pioneer Brand Maize Hybrids for Grain). Among the ME yield components, ME grain was only moderately correlated to whole crop digestibility. ME of non-grain components was strongly associated with whole crop digestibility. This suggests that whole crop ME content is dependent on the ME of all components and not just % grain in total DM. The variation in ME content of maize plant components in this study is in agreement with earlier results (Roth, et. al., 1970; Vattikonda and Hunter, 1983 Deinum et. al. 1984; Pinter et. al. 1986; Roth et. al, 1987. ; Wolf et. al. 1993a,b). Allen (1992) reported that because of differences in stover quality, a silage with 30% grain may contain more digestible energy than a silage with 50% grain. In addition, two hybrids with 45% of total yield as grain may have large differences in digestibility. The results from the present study contradict the generally accepted belief that a good grain hybrid produces a high yielding high quality silage. This study suggests that high quality silage can be produced by selecting hybrids high in both stover digestibility and high grain yields. Recent research emphasis on maize silage is now placed on increasing grain content and stover digestibility (Minson et. al. 1993).

Allen (1992) and Struik (1985) reported many different factors attributed to differences in whole crop digestibility, e.g. environment and management factors. However, comparison of whole crop digestibility among plant population levels cannot be made in this study. Existing literature states that high plant population increases cell wall content and consequently reduces digestibility (Deinum and Struik, 1986). The ME values obtained in this study were higher than those obtained in the dairying districts of New South Wales (Kaiser et. al. as cited by Minson et. al., 1993). These researchers found that low ME values were associated with stressed crops, especially when stress occurred late in the crop's development during grain filling. Earlier reports indicated that high temperatures (30°C day/24°C night) stimulated cell wall development and thereby reduces digestibility (Struik, 1983). However, the present study did not include determination of fiber content and fiber digestibility, thus further discussion is not possible.

Maize silage does have limitations as a complete feed if feed as 100% of the diet. It is low in crude protein (total N % x 6.25 to arrive at the crude protein value) and may require supplementation to correct its inherent deficiencies (Barry et. al. 1980). In the present study, overall N % ranges from 1.05% (6.56% protein) (Furio) to 1.16% (7.25% protein) (Janna and CF1). These levels are similar to those obtained by Thom et. al. (1981). It is worth mentioning that N ratings of P3902, P3751 and P3585 in the current study did not differ significantly from the seed company's N rating (1995/96 Pioneer Brand Maize Hybrids for Grain). N % is closely related to stage of maturity at harvest (Fairey, 1982) and varies due to soil N (Pierre et. al. 1977), soil K (Keeney, 1969), climatic conditions (Bird and Olson, 1972; Earle, 1977) and genetic factors

(Alexander and Creech, 1977). Bullock et. al. (1989) found that maturity grouping had no effect on protein concentration. Iremiren and Milbourn (1978) studied the quality components of 2 maize silage hybrids. They found that crude protein percentage in leaf, stem and ear and whole-shoot did not differ between hybrids.

In dairy feeding systems, silage must be of high quality. Maize is a crop well suited to this purpose with its ability to supply metabolizable energy of at least 8.5 MJ/kg DM corresponding to dry matter digestibility value of 60% necessary to maintain milk yields in dairy cows (Cowan and Kerr, 1984). However, maize as mentioned earlier, is deficient in protein.

There may be a need for supplemental protein when feeding maize silage, depending on the quantity of protein available in other feed sources and on the level of silage feeding. Davison et.al. (1982) reported that an addition of protein supplement can increase milk production by 2 to 3 kg milk/cow/day with the objective to have an average of 14% crude protein in the total diet (Cowan and Kerr, 1984). Waghorn and Wilson (1974) concluded that protein deficiency of maize silage could be overcome by supplementation with small quantities of fresh pasture. Other reports indicated that if maize silage is fed as a supplement to pasture such that no more than 30 to 40% of the DM intake comes from maize silage, the cows diet will be balanced and high levels of milk production can be achieved (Department of Animal Science, Massey Univ, 1986).

5.7 RELATIONSHIPS BETWEEN YIELD, DRY MATTER PARTITIONING AND FEED QUALITY

Metabolizable energy yield (MEY) in the present study is almost completely ($r=0.97$) determined by total dry matter yield (TDM). This suggests that improvement in MEY can probably only be achieved by increasing TDM (Geiger et. al. 1992). Deinum and Bakker (1981) studied the variation in yield and digestibility among 27 maize hybrids. They reported estimates of the genotypic coefficient of variation (CV) to be five times greater for silage yield than for silage digestibility. A similar pattern was also observed by Geiger et. al. (1992).

The ME values for the yield components were negatively correlated with % grain. Fairey (1982) found that the digestibility of whole-plant maize DM was significantly but not closely related ($r=0.28$) to % grain while stover digestibility was negatively correlated (-0.45) with % grain, indicating that the nutritive value of the stover declined with increasing grain growth. Deinum and Bakker (1981) and Vatikonda and Hunter (1983) also observed that forage digestibility was more affected by stover digestibility than by grain proportion of total dry matter. In a recent study, Argillier et.al. (1995) found that grain yield was not significantly correlated with the whole-plant composition nor with digestibility. It has to be emphasized however, that both grain and stover components are of equal importance in the determination of the nutritive value of maize silage hybrids. A proportion of grain is desirable, being a highly digestible component, but it is not a good predictor of silage energy content because of the large variation in fibre content and fibre digestibility of stover (Allen, 1992). Growers then, may wish to consider hybrid quality characteristics in addition to dry matter yields

before selecting a hybrid to plant. Further, the strong significant negative correlations between % grain and stem and leaf % suggests that grainfilling benefits from the translocation of DM from the stem and leaf portion of the plant. This was demonstrated by the great magnitude of reduction in the stem and leaf weights at final harvest which cannot be all attributed to the loss through respiration. This period coincided with the time of high dry matter accumulation in the grains. In addition, the practice of recommending hybrids for silage production based on grain yields may be counter productive. This is illustrated by the negative correlation between grain % and quality parameters at the time of harvest for silage.

The strong correlation ($r=0.82$) between % grain and NHI suggests that they are closely related each other. Ahmadi et. al. (1993) obtained a parallel relationship between % grain and NHI. This indicates that the remobilization of DM and N during grain-filling in maize are related. The non-correlations between final yield and N% yield components and N% of total dry matter agrees with the observation of Vattikonda and Hunter (1983). This suggests the possibility of choosing hybrids with a high protein % without having to accept a low whole-plant final yield. N% of total dry matter, as expected was related to N% of yield components. It has to be mentioned however, that maize silage is grown primarily as energy feed and N% is not of primary concern because protein-rich pastures and legumes are also produced on most livestock farms.

A strong positive association between N yield and final DM yield indicates that N yield is dependent on DM yield. Grain yield however, was weakly correlated with % grain. These relationship further reinforced the earlier statement indicating that it may

be possible to select maize hybrids that will have high N, and high yield.

Hybrid selection is an important management input because it influences the nutritive value of maize silage. Among the six commercial maize silage hybrids (CF1 is excluded being a non-commercial hybrid at the time of experiment) tested under Manawatu conditions, P3902, Furio, P3585 are the preferred hybrids for early, medium and full season, respectively. These hybrids fell into the high yield (>17 t/ha) high quality (>10 MJME/kg DM) category. Further, the promising performance of CF1, being the best among the hybrids tested in the current study in terms of yield (20 t/ha) and nutritive quality (11.3 MJME/kg DM), demonstrated the benefits of improving the agronomic and quality characteristics of maize hybrids for silage production in New Zealand through local plant breeding programmes. Hybrids bred locally may be better adapted to the cooler New Zealand summer temperatures than those hybrids of North American Corn Belt origin.

CONCLUSIONS

Results of this study showed that under Manawatu conditions:

- 1) Average temperature for the 1994/95 season was 0.6°C warmer than the long term average. Rainfall was variable during the growing season with November, March and April being well above normal average. December to February had lower than normal precipitation.
- 2) Plant height and leaf number differed significantly among hybrids and was related to maturity ranking. Full season hybrids were taller and produced more leaves than medium and early season hybrids.
- 3) The effect of hybrid on duration of crop growth was closely related to hybrid relative maturity.
- 4) Whole crop dry matter yield at final harvest differed significantly among hybrids ranging from 15,776 to 20,046 kg DM/ha. CF1 achieved the highest yield significantly greater than Janna, Furio, P3751 and CG900. Janna was the lowest yielding hybrid.
- 5) The study confirmed the present recommended plant population of 100,000 plants per hectare for maize silage in New Zealand.
- 6) Whole crop metabolizable energy contents ranged from 11.32 MJME/kg DM to 10.28 MJME/kg DM. CF1 had significantly higher ME content than all other hybrids.
- 7) Dry matter partitioning was influenced by hybrid at 50% silking and final harvest. However, plant population had little effect on dry matter partitioning.
- 8) Total metabolisable energy (TME) content was influenced by the ME in the grain, leaf, husk and stem.
- 9) N % of total dry matter did not vary significantly among hybrids ranging from 1.07 to 1.6%. N % of total dry matter was strongly correlated to N % in the grain and moderately correlated to N % in the stem and N % in the leaf.
- 10) NHI was highly correlated with % grain suggesting that remobilisation of DM and N during crop maturation are related.

11) Hybrid CF1 was the best performing hybrid having the highest yield, metabolisable energy and N %. This indicates a considerable potential for improving the agronomic characteristics of maize hybrids for silage production in New Zealand through local plant breeding programmes.

12) The proportion of grain in the final yield was not a good indicator of forage quality.

REFERENCES

- Abasi, L.; Fakorede, M. A. B.; Alofe, C. O., 1985
Comparison of heat units and calendar days for predicting silking dates in maize in a tropical rainforest location
Maydica 30:15-30
- Adelana, B. O.; Milbourn, G. M., 1972a
The growth of maize. I. The effect of plant density on yield of digestible dry matter and grain.
Journal of Agricultural Science (Cambridge) 78:65-71
- Adelana, B. O.; Milbourn, G. M., 1972b
The growth of maize. II. Dry matter partition in three maize hybrids
Journal of Agricultural Science (Cambridge) 78:73-78
- Afuakwa, J. J.; Crookston, R. K., 1984
Using the kernel milkline to usually monitor grain maturity in maize
Crop Science 24:687-691
- Ahmadi, M.; Wiebold, W. J.; Beuerlein, J. E.; Eckert, D. J.; Schoper, J., 1993
Agronomic practices that affect corn kernel characteristics
Agronomy Journal 85:615-619
- Al-Darby, A. M. and Lowery, B., 1987
Seed zone soil temperature and early corn growth with three conservation tillage systems
Soil Science Society of America Journal 51:768-774
- Alberda, T. H., 1962
Actual and potential production of agricultural crops
Netherlands Journal of Agricultural Science 5:325-333 Special Issue.
- Aldrich, S. R.; Leng, E. R., 1966
Modern corn production
The farm quarterly. Cincinnati, Ohio, U.S.A.
- Alessi, J.; Power, J. F., 1974
Effects of plant population, row spacing, and relative maturity on dryland corn in the northern plains. I. Corn forage and grain yield
Agronomy Journal 66:316-19
- Alessi, J.; Power, J. F., 1975
Response of an early-maturing corn hybrid to planting date and population in the northern plains
Agronomy Journal 67:762-765

- Alessi, J.; Power, J. F., 1971
Corn emergence in relation to soil temperature and seedling depth
Agronomy Journal 63:717-719
- Alexander, D. E.; Creech, R. G., 1977
Breeding special industrial and nutritional types
In: GF. Sprague (ed.) *Corn and corn improvement*
Agronomy 5:363-390
- Allen, M., 1992
Hybrid differences in corn silage forage quality
Proc 1992 16th Annual Forage Symposium and Meeting. Wisconsin Forage Council, Wisconsin Dells, WI. Jan 28-29, 1992
- Allen, M. S.; O'Neil, K. A.; Dado, R. G.; Kohn, R. A., 1992
Variation in fibre content and fibre digestibility of corn forages
Minnesota Forage. Late Summer 1992. Vol. XVII No. 4. Mich. State Univ., East Lansing, MI
- Allison, J. C. S., 1969
Effect of plant population on the production and distribution of dry matter in maize
Annals of Applied Biology 63:135-144
- Allison, J. C. S.; Watson, D. J., 1966
The production and distribution of dry matter in maize after flowering
Annals of Botany. 30(119):365-381
- Andrew, R. H.; Peek, J. W., 1971
Influence of cultural practice and field environment on consistency of corn yields in northern areas
Agronomy Journal 63:628-633
- Andrews, C. J., 1987
Low temperature stress in field and forage crop production an overview
Canadian Journal of Plant Science 67:1121-1133
- Andrieu, J.; Demarquilly, C., 1974
Feeding value of maize forage. II. Effect of growth stage, variety, crop density, artificial ear enrichment, urea addition on digestibility and voluntary intake of maize silage
Annales Zootechnie 23(1)1-25
- Argillier, O.; Hebert, Y.; Barriere, Y., 1995
Relationships between biomass yield, grain production, lodging susceptibility and feeding value in silage maize
Maydica 40:125-136

- Balko, L. G.; Russel, W. A., 1980
Effects of rates of nitrogen fertiliser on maize inbred lines and hybrid progeny.
I. prediction of yield response
Maydica 25:65-79
- Bansal, R. K.; Eagles, H. A. 1985
History and present status of maize production in New Zealand. pp. 3-7.
In: H. A. Eagles, G. S. Wratt, Editors, *Maize: Management to Market*. Special
Publ. No. 4. Agronomy Society of New Zealand
- Barghoorn, E. S.; Wolfe, M. K.; Clisby, K. H., 1954
Fossil maize from the Valley of Mexico
Botanical Museum Leaflets, Harvard University 16:229
- Barnes, D. L.; Woolley, D. G., 1969
The effect of moisture stress at different stages of plant growth. I. Comparison
of a single-eared and a two-eared corn hybrid
Agronomy Journal 61:788-790
- Barry, T. N.; Marsh, R.; Reardon, T. F.; A. South., 1980
Conservation and utilization of silage and hay. pp. 107-152
In: K. R. Drew, P. F. Fenessy (eds.). *Supplementary Feeding- a guide to the
production of feeding supplements*. A New Zealand Society of Animal
Production Publication
- Basak, M. N.; Sen, S. K.; Bhattacharjee, P. K., 1962
Effects of high nitrogen fertilization and lodging on rice yield
Agronomy Journal 54:477-480
- Bassetti, P.; Westgate, M. E., 1993
Water deficit affects receptivity of maize silks
Crop Science 33:279-281
- Beauchamp, E. G.; Kannenberg, L. W.; Hunter, R. B., 1976
Nitrogen accumulation and translocation in corn genotypes following silking
Agronomy Journal 68:418-422
- Berard, R. G.; Thurtell, G. W., 1991
The interactive effects of increased evaporative demand and soil water on
photosynthesis in maize
Canadian Journal of Plant Science 71:31-39
- Berger, J., 1962
Maize production and manuring of maize
Centro d'Etude de l'Azote, Geneva. 315pp

- Berry, P.S., 1977
Obtaining high yields of maize
In: D.A.L. Buxton (ed.). Proc. South Taranaki Grain Seminar. Memorial Theatre, Hawera. 7th September 1977
- Bird, H. R.; Olson, D. W., 1972
Effect of fertilizer on the protein and amino acid of yellow corn and implications for feed formulation
Poultry Science 51:1353-1358
- Biscoe, P. V.; Gallagher, J. N., 1976
A physiological analysis of cereal yield. I. Production of dry matter
Agricultural Progress 51:34-50
- Blacklow, W. M., 1972
Influence of temperature on germination and elongation of the radicle and shoot of corn
Crop Science 12:47-650
- Bland, B. F., 1971
Crop production: cereals and legumes
Academic Press: London and New York. 466pp.
- Bonaparte, E. E. N. A., 1975
The effects of temperature, daylength, soil fertility and soil moisture on leaf number and duration to tassel emergence in *Zea mays* L.
Annals of Botany 39:853-861
- Bonciarelli, F.; Monotti, M., 1975
Growth analysis of hybrid corn of different earliness
Maydica. 20:39-55
- Boyle, M. G.; Boyer, J. S.; Morgan, P. W., 1991
Stem infusion of liquid culture medium prevents reproductive failure of maize at low water potential
Crop Science 31:1246-1252
- Brooking, I. R.; McPherson, H. G., 1989
The impact of weather on the scheduling of sweet corn for processing. I. Quantifying the link between rate of development and the environment
New Zealand Journal of Crop Horticultural Science. 17:19-26
- Brouwer, R., 1962
Distribution of dry matter in the plant
Netherlands Journal of Agricultural Science 10(5):361-376

- Brown, D. M., 1978
Heat units for corn in southern Ontario
Ontario MAF Factsheet Ag dev 111/31 Order No. 78-063
- Brown, R. H.; Beaty, E. R.; Ethredge, W. J.; Hayes, D. D., 1970
Influence of row width and plant population on yield of two varieties of corn (*Zea mays* L.)
Agronomy Journal 62:767-770
- Brown, D. M., 1986
Corn yield response to irrigation, plant population and nitrogen in a cool humid climate
Canadian Journal of Plant Science 6:453-464
- Bryant, H. T.; Blaser, R. E. 1968
Plant constituents of an early and late corn hybrid as affected by row spacing and plant population
Agronomy Journal 60:557-559
- Bullock, D. G.; Raymer, P. L.; Savage, S., 1989
Variation of protein and fat concentration among commercial corn hybrids grown in the southwestern USA.
Journal of Production Agriculture 2:157-161
- Bundy, L. G.; Carter, P. R., 1988
Corn hybrid response to nitrogen fertilizer in the Northern Corn Belt.
Journal of Production Agriculture 1:99-104
- Bunting, E. S., 1978
Agronomic and physiological factors affecting forage maize production
In: E. S. Bunting, B. F. Oin, R. H. Phipps, J. M. Wilkinson and R. E. Gunn (eds.). Forage Maize. Agricultural Research Council London. 1978
- Bunting, E. S., 1971
Plant density and yield of shoot dry material of maize in England
Journal of Agricultural Science (Cambridge) 77:175-185
- Bunting, E. S., 1975
The question of grain content and forage quality in maize: comparison between isogenic fertile and sterile plants
Journal of Agricultural Science (Cambridge) 85:455-463
- Bunting, E. S., 1968
The influence of date of sowing on development and yield of maize in England
Journal of Agricultural Science (Cambridge) 71:117-125

- Bunting, E. S., 1973
Plant density and yield of grain maize in England.
Journal of Agricultural Science (Cambridge) 81:455-463
- Buxton, D.A.L. 1974
The growing and utilization of maize for greenfeed and silage
Proceeding Agronomy Society of New Zealand 4:97-100
- Buxton, D. A. L., 1975
Maize Greenfeed-Maize Silage
MAF New Zealand. 26pp
- Buxton, D. R.; Casler, M. D., 1993
Environmental and genetic effects on cell-wall composition and digestibility. p.
685-714
In: H. G. Jung (ed) *Forage cell wall structure and digestibility*. ASA, CSSA, and
SSSA, Madison, WI
- Calder, F. W.; Langile, J. E.; Nicholson, J. W. G., 1977
Feeding value for beef steers of corn silage as affected by harvest dates and frost
Canadian Journal of Animal Science 57:65-73
- Caldwell, A. C.; Ohlrogge, A.J. 1966
Phosphorous fertility requirement. 238-250 pp.
In: *Advances in corn production* (eds.) W. H. Pierre, S. R. Aldrich, W. P.
Martin. The Iowa Univ. Press. 1966
- Camery, M. P.; Weber, C. R., 1953
Effects of certain components of simulate hail injury on soybeans and corn
Iowa Agricultural Experiment Station Research Bulletin 400
- Cardwell, V. B., 1982
Fifty years of Minnesota corn production: Source of yield increase
Agronomy Journal 74:984-990
- Carr, M. K. V.; Hough, M. N., 1978
The influence of climate on maize production in North-Western Europe. pp.15-55
In: E. S. Bunting, R. H. Phipps, J. M. Wilkinson, R. E. Gunn (eds.). *Forage
maize*. Agricultural Research Council. 1978
- Carter, P. R.; Hendelson, K. D., 1988
Influence of simulated wind lodging on corn growth and development
Journal of Production Agriculture :295-299
- Castle, M. E.; Watson, J. N. 1973
The relationship between the dry matter content of herbage for silage making and
effluent production
Journal of British Grassland Society 28:135-138

- Castleberry, R. M.; Crum, C. W.; Krull, C. F., 1984
Genetic yield improvement of US maize cultivars under varying fertility and climatic environments
Crop Science 24:33-36
- Chang, J. H. 1981
Corn yield in relation to photoperiod, night temperature and solar radiation
Agricultural Meteorology 24:253-262.
- Chappel, P. L., 1985
Uses and processing of grain maize in New Zealand. pp. 9-12
In: H. A. Eagles, G. S. Wratt (eds.) Maize-Management to Market. Agronomy Society of New Zealand Special Pub. No. 4 (Lincoln, NZ)
- Chase, S. S.; Nanda, D. K., 1967
Number of leaves and maturity classification in *Zea mays* L.
Crop Science 7:431-432
- Chaudhary, T. N.; Bhatnagar, V. B.; Prihar, S. S., 1975
Corn yield and nutrient uptake as affected by water table depth and soil submergence
Agronomy Journal 67:745-749
- Cheng, P. C.; Pareddy, D. R., 1994
Morphology and development of the tassel and ear. pp. 37-47
In: M. Freeling, V. Walbot (eds.) The Maize Handbook, Springer-Verlag, NY Inc
- Claasen, M. M.; Shaw, R.H., 1970b
Water deficits on corn grain components
Agronomy Journal 62:652-655
- Claasen, M. M.; Shaw, R.H. 1970a
Water deficit effects on corn. I. Vegetative components
Agronomy Journal 62:649-652
- Coelho, D. J.; Dale, R.F., 1980
An energy-crop growth variable and temperature function for predicting corn growth and development: planting to silking
Agronomy Journal 72:503-510
- Coligado, M. C.; Brown, D. M., 1975
A bio-photothermal model to predict tassel-initiation time in *Zea mays* L.
Agricultural Meteorology 15:11-31
- Colville, W. L.; McGill, D. P., 1962
Effect of rate and method of planting on several plant characters and yield of irrigated corn
Agronomy Journal 54:235-238

- Connel, M. J. 1985
Hybrid seed maize production. pp. 67-69
In: H. A. Eagles, G. S. Wratt (eds.) Maize-Management to Market. Agronomy Society New Zealand Special Publication No. 4 (Lincoln, NZ)
- Cooper, R. L. 1971
Influence of early lodging on yield of soybean
Agronomy Journal 63:449-450
- Cowan, R. T.; Kerr, D. V., 1984
Dairy feeding systems based on pasture and forage crop silage in the tropics and sub-tropics. pp. 384-391
In: T. J. Kempton, A. G. Kaiser, T. E. Trigg. Silage in the 80's National Workshop Armidale, New South Wales
- Craig, W. F., 1966
Prediction factors for corn silage production
Dissertation Abstracts 21:2988-93
- Crampton, E. W.; Harris, L. E., 1969
Applied animal nutrition
W.H. Freeman and Company. San Francisco. pp.753
- Craswell, E. T.; Goodwin, D. C. 1984
The efficiency of nitrogen fertilizers applied to cereals in different climates. pp.1-55
In: P. B. Tinker and A. Lauchli (eds.) Advances in Plant Nutrition. Vol. 1. Praeger Scientific, New York
- Crookston, R. K.; Kurle, J. E. 1988
Using the kernel milkline to determine when to harvest corn for silage
Journal of Production Agriculture 1:293-295
- Cumberland, G. L. B.; Blackmore, L. W.; Cottier, K.; Douglas, J. A.; Nixon, G. W.; Thompson, A. 1971
Performance of hybrid maizes (*Zea mays* L.) in field trials
Proceeding First Annual Conference Agronomy Society of New Zealand. Aug. 24-16, 1971. Lincoln College, Canterbury, New Zealand
- Cummins, D. G., 1970
Quality and yield of corn plants and component parts when harvested for silage at different maturity stages
Agronomy Journal 62:781-784
- Cummins, D. G.; Dobson, J. W., 1973
Corn for silage as influenced by hybrid maturity, row spacing, plant population and climate
Agronomy Journal 65:240-243

- Cummins, D. G. 1975
Influences of planting date, hybrid maturity, and plant population on production and quality of irrigated and non-irrigated corn for silage
Georgia Agricultural Experiment Station Research Bulletin 178
- Cutworth, H. W.; Shaykewich, C. F., 1990
A temperature response function for corn development
Agriculture for Meteorology 50:159-171.
- Davison, T. M.; Orr, W. N.; Clark, R., 1984
Changes in silage use on the Atherton Tablelands, North Queensland. pp. 392-396
In: T.J. Kempton, A.G. Kaiser, T.E. Trigg. Silage in the 80's National Workshop
Armidale, New South Wales
- Davison, T. M.; Marschke, R. J.; Brown, G. W., 1982
Milk yields from feeding maize silage and meat-and-bone meal to Friesian cows grazing a tropical grass and legume pasture
Australian Journal of Experimental Agriculture and Animal Husbandry 22:147-154
- Daynard, T. B.; Muldoon, J. F., 1981
Effects of plant density on the yield, maturity and grain content of the whole-plant maize
Canadian Journal of Plant Science 61:843-849
- Daynard, T. B., 1978
Practices affecting quality and preservation of whole-plant corn silage
Canadian Journal of Plant Science 58:651-659
- Daynard, T. B., 1972
Relationships among black layer formation, grain moisture percentage and heat unit accumulation in corn
Agronomy Journal 64:716-719
- Daynard, T. B.; Tanner, J. W.; Hume, D. J., 1969
Contribution of stalk soluble carbohydrates to grain yield in corn (*Zea mays* L.)
Crop Science 9:831-834
- Daynard, T. B.; Hunter, R. B., 1975
Relationships among whole-plant moisture, grain moisture, dry matter yield and quality of whole corn silage
Canadian Journal of Plant Science 55:77-84
- Daynard, T. B.; Duncan, W. G., 1969
The blacklayer development in corn
Agronomy Journal 63:303-305

- Daynard, T. B.; Arnold, R. L.; Bellman, H. E., 1978
Density-pressure seepage relationships of whole plant corn (*Zea mays* L.) silage
Canadian Agricultural Engineering 20(1):45-52
- Daynard, T. B.; Duncan, W. G., 1969
The blacklayer and grain maturity in corn
Crop Science 9:473-476
- Daynard, T. B. 1978
Practices affecting quality and preservation of whole-plant corn silage
Canadian Journal of Plant Science 58:651-659
- Deinum, B.; Knoppers, J., 1979
The growth of maize in the cool temperate climate of the Netherlands: Effect of grain filling on production of dry matter and on chemical composition and nutritive value
Netherlands Journal of Agricultural Science 27:116-130
- Deinum, B.; Struik, P. C., 1986
Improving the nutritive value of forage maize. p.77-90
In: O. Dolstra and P. Miedema (eds.) Breeding of silage maize Proc. 13th congress on the maize and sorghum section of Eucarpia Wageningen, The Netherlands. 9-12 Sept. 1985. Pudoc, Wageningen, The Netherlands
- Deinum, B.; Baker, J. J., 1981
Genetic differences in digestibility of forage maize hybrids
Netherlands Journal of Agricultural Science 29:93
- Deinum, B. A.; Hof, G., 1984
Measurement and prediction of forage maize in the Netherlands
Animal Feed Science and Technology 10:301-313
- Deloughery, R. L.; Crookston, R. K., 1979
Harvest index of corn affected by population density, maturity rating and environment
Agronomy Journal 71:577-580
- Denmead, O. T.; Shaw, R. H., 1960
The effects of soil moisture stress at different stages of growth on the development and yield of corn
Agronomy Journal 52:272-274
- Department of Animal Science., 1986
Feeding value of crops
Massey University

- Derieux, M.; Bonhomme, R., 1982
Heat unit requirements for maize hybrids in Europe. results of the European
FAO Sub-Network. I. Sowing-silking period
Maydica 27:59-77
- Dhillon, B. S.; Paul, C.; Zimmer, E.; Gurrath, P. A.; Klein, D.; Pollmer, W. G., 1990
Variation and covariation in stover digestibility traits in diallel crosses of maize
Crop Science 30:931-936
- Donald, C. M.; Hamblin, J., 1976
The biological yield and harvest index of cereals as agronomic and plant
breeding criteria
Advances in Agronomy 28:361-405
- Doss, B. D. 1974
Comparison of fog irrigation with surface irrigation in corn production
Agronomy Journal 66:105-107
- Douglas, J. A.; Dyson, C. B., 1972
The use of a systematic spacing design in plant densities
Proceedings Agronomy Society of New Zealand 2:39-47
- Douglas, J. A. 1980
Yields of crops for forage and fodder. pp1-43
In: K.R. Drew and P.F. Fennessy. (eds.) *Supplementary Feeding- a guide to the
production of feeding of supplements.* A New Zealand Society of Animal
Production Publication
- Douglas, J. A.; Cottier, K.; Kain, W. M.; O'Connor, M. B.; Southon, T., 1972
Advances in maize production
Proceeding Ruakura Farmers'Conference 121-128
- Dubetz, A.; Russel, G. C.; Anderson, D. T., 1962
Effect of soil temperature on seedling emergence
Canadian Journal of Plant Science 42:48-487
- Duncan, E. R.; Schaller, F. W., 1962
Continuous corn profitable on both sides
Plant Food Review, Winter p3-5
- Duncan, E. R., 1966
Problems relating to selection of hybrid seed:calendarization a consideration. pp.
104-119
In: W. H. Pierre, S. R. Aldrich, W. P. Martin (ed.) *Advances in corn production.*
The Iowa State Univ. Press, Ames, Iowa, USA

- Duncan, W. G., 1958
The relation between corn population and yield
Agronomy Journal 50:82-85
- Duncan, W. G., 1975
Maize. pp.23-50
In: L. T. Evans (ed.) *Crop physiology:some case histories* Cambridge Univ. Press
- Duncan, W. G.; Hesketh, J. D., 1968
Net photosynthetic rates, relative leaf growth and leaf numbers of 22 races of maize grown at night temperatures
Crop Science 8:670-674
- Duncan, W. G., 1984
A theory to explain the relationship between corn population and grain yield
Agronomy Journal 24:1141-1145
- Dungan, G. H.; Lang, A. L.; Pendleton, J. W., 1958
Corn plant population in relation to soil productivity
Advances in Agronomy. Vol 10:435-473
- Duvick, D. N., 1984
Genetic contributions to yield gains of US hybrid maize 1930 to 1980
Genetic Contributions to Yield Grains of Five Major Crop Plants (W. R. Fehr. ed.), CSSA Spec. Publ. 7., CSSA Madison, WI. pp. 15-47.
- Duvick, D. N., 1992
Genetic contributions to advances in yield of US maize
Maydica. 37:69-79
- Duvick, D. N., 1977
Genetic rates of gain in hybrid maize yields during the past 40 years
Maydica. 22:187-196
- Dwyer, L. M.; Tollenaar, M.; Stewart, D. W., 1991
Changes in plant density dependence of leaf photosynthesis of maize hybrids, 1959 to 1988
Canadian Journal of Plant Science 71:1-11
- Dwyer, L. M.; Hahoe, H. N.; Culley, J. L. B., 1990
Prediction of soil temperature from air temperature for estimating corn emergence
Canadian Journal of Plant Science 70:619-628
- Dwyer, L. M.; Stewart, D. E.; Evenson, L.; Ma, B.L., 1994
Maize growth and yield following late summer hail
Crop Science 34:1400-1403

- Earle, F. R., 1977
Protein and oil in corn : Variation by crop years from 1907 to 1972
Cereal Chemistry 54:70-79
- Early, E. B.; Miller, R. J.; Reichert, G. L.; Hagemann, R. H. Hagemann; Sief, R. D., 1966
Effects of shade on maize production under field conditions
Crop Science 6:1-6
- Eckert, D. J.; Martin, V.L., 1994
Yield and nitrogen requirement of no-tillage corn as influenced by cultural practices
Agronomy Journal 86:1119-1123
- Eddowes, M., 1969
Physiological studies of competition in *Zea mays*. III. Competition in maize and its practical competitions for forage maize production
Journal of Agricultural Science (Cambridge) 72:203-215
- Edmeades, G., 1972
Maize plant population and subsequent yield
In: B. J. Hockings (ed) Maize Field Day-Summary of Proceedings, Massey University 23 March 1972
- Edmeades, G. O.; Daynard, T. B., 1979
The development of plant-to-plant variability in maize at different planting densities
Canadian Journal of Plant Science 59:561-576
- Edmeades, G. O.; Tollenaar, M., 1990
Genetic and cultural improvements in maize production
Proc. of the International Congress of Plant Physiology, New Delhi. pp. 164-180
- Fageria, N. K., 1992
Nutrient use efficiency in crop production. pp. 125-163
In: N.K Fageria. Maximizing crop yields. Marcel Dekker, Inc.
- Fairey, N. A., 1982
Influence of population density and hybrid maturity on productivity and quality of forage maize
Canadian Journal of Plant Science 62:427-434
- Fairey, N. A., 1980
Hybrid maturity and the relative importance of grain and stover for the assessment of the forage potential of maize genotypes grown in marginal and non-marginal environments
Canadian Journal of Plant Science 60:539-545

- Fakorede, M. A. B.; Mock, J. J., 1982
Correlated responses to recurrent selection for grain yield in maize
Iowa State University Experiment Station Research Bulletin 596
- Feil, B; Thiraporn, R.; Lafittee, H. R., 1993
Accumulation of nitrogen and phosphorous in the grain of tropical maize cultivars
Maydica 38:291-300
- Fery, R.L.; Janick, J., 1971
Response of corn (*Zea mays* L.) to population pressure
Crop Science 11:220-224
- Fischer, L. J.; Fairey, N. A., 1982
The effect of planting density on the nutritive value of corn silage for lactating cows
Canadian Journal of Animal Science 62:1143
- Fischer, K. S.; Palmer, A. F. E., 1984
Tropical maize. pp.213-248
In: P. R. Goldsworthy, N. M. Fisher (eds.). The physiology of tropical field crops. John Wiley and Sons. 664pp
- Fisher, L. J.; Sogan, V. S.; Donovan, L. S.; Carson, R. B., 1968
Factors influencing dry matter intake and utilisation of corn silage by lactating cows
Canadian Journal of Animal Science 48:207-214
- Food and Agriculture Organization., 1992
Maize in human nutrition
FAO Food and Nutrition Series No. 25
- Francis, C. A.; Sarria, D.; Harpsted, D.; Cassalet, C., 1972
Identification of photoperiod insensitive strains of maize. II. Field tests in the tropics with artificial lights
Crop Science 10:465-468
- Francis, C. A.; Grogan, C. O.; Sperling, D. W., 1969
Identification of photoperiod insensitive strains of maize
Crop Science 9:675-677
- Gaasta, P., 1962
Photosynthesis of leaves and field crop
Netherlands Journal of Agricultural Science 10(5):311-324 Special Issue
- Gallais, A.; Pollacsek, M.; Huguet, L., 1976
Possibilites de selection du maïs en tant que plante fourragere
Annales d'amelioration des Plantes 26:591-605

- Ganoe, K. H.; Roth, G. W., 1992
Kernel milkline as a harvest indicator for corn silage in Pennsylvania
Journal of Production Agriculture 5:519-523
- Gardner, C. A. C.; Bac, P. L.; Bailey, D. J.; Cavalieri, A. J.; Calusen, C. R.; Luce, G. A.; Meece, J. M.; Murphy, P. A.; Piper, T. E.; Segebart, R. L.; Smith, O. S.; Tiffany, C. W.; Trimble, M. W.; Wilson, B. N., 1990
Response of corn hybrids to nitrogen fertilizer
Journal of Production Agriculture 3:39-43
- Geiger, H. H.; Seitz, G.; Melchinger, A. E.; Schmidt, G. A., 1992
Genotypic correlations in forage maize. I. Relationship among yield and quality traits in hybrids
Maydica 37:95-99
- Genter, C. F.; Camper, H. M. Jr., 1973
Component plant part development in maize as affected by hybrids and population density
Agronomy Journal 63:669-671
- Genter, C. F.; Jones, G. D.; Carter, M. T., 1970
Dry matter accumulation and depletion in leaves, stems and ears of maturing maize
Agronomy Journal 62:535-537
- Gilmore, E. C.; Rogers, J. S., 1958
Heat units as a method of measuring maturity in corn
Agronomy Journal 50:611-615
- Gmelig Meyling, H. D., 1973
Effect of light intensity, temperature and daylength on the rate of leaf appearance of maize
Netherlands Journal of Agricultural Science 21:68-76
- Goering, H. K.; Hemken, R. W.; Clark, N. A.; Vandersall, J. H., 1969
Intake and digestibility of corn silages of different maturities and plant populations
Journal of Animal Science 29:512-518
- Goldsworthy, P. R.; Palmer, A. F. E.; Sperling, D. W., 1974
Growth and yield of lowland tropical maize in Mexico
Journal of Agricultural Science (Cambridge) 83:223-230
- Gordon, C. H., 1967
Storage losses in silage as affected by moisture content and structure
Journal of Dairy Science 50:397-403

- Graybill, J. S.; Cox, W. J.; Otis, D. J., 1991
Yield and quality of forage maize as influenced by hybrid, planting date and plant density
Agronomy Journal 83:559-564
- Gunn, R. E. 1978
Forage maize breeding and seed production. p.133-151
In: E. S. Bunting et. al. (ed). Forage maize:production and utilization. Agric. Res. Council, London
- Gunn, R. B.; Christensen, R., 1965
Maturity relationship among early to late hybrids of corn
Crop Science 5:299-302
- Gupta, S. C.; Larson, W. E.; Linden, D. R., 1983
Tillage and surface residue effects on soil upper boundary temperatures
Soil Science Society America Journal 47:1212-1218
- Haggar, R. J.; Couper, D. C., 1972
Effects of plant population and fertilizer nitrogen on growth and components of yield of maize grown for silage in Nigeria
Experimental Agriculture 8:251-263
- Hallauer, A. R.; Russel, W. R., 1962
Estimates of maturity and its inheritance in maize
Crop Science 2:289-294
- Hanway, J. J.; Russel, W. A., 1969
Dry matter accumulation in corn (*Zea mays* L.) plants:comparisons among signal-cross hybrids
Agronomy Journal 61:947-951
- Hanway, J. J., 1962
Corn growth and composition in relation to soil fertility. II. Uptake of N, P, K and their distribution in different plant parts during the growing season
Agronomy Journal 54:217-222
- Hanway, J. J., 1962
Corn growth and composition in relation to soil fertility. I. Growth of different plant parts and relation between leaf weight and grain yield
Agronomy Journal 54:145-148
- Hanway, J. J. 1966
How a corn plant develops
Special Report No. 48. Iowa State Univ. of Sci. and Tech. Cooperative Extension Service, Ames, Iowa-September 1966

- Hardacre, A. K.; Sinclair, K. I.; van Tilburg, M. P., 1991
Maize: a guideline for growers
Agriculture Bulletin No. 18.
- Hasfurther, V. R.; Burman, R. O., 1974
Soil temperature modelling using air temperature as a driving mechanism
Transaction American Society of Agricultural Engineering 17:78-81
- Hatlitligil, M. B.; Olson, R. A.; Campton, W. A., 1984
Yield, water use and nutrient uptake of corn hybrids under varied irrigation and nitrogen regimes
Fertilizer Research 5:321-333
- Hay, R. K. M., 1995
Harvest index: a review of its use in plant breeding and crop physiology
Annals of Applied Biology 126:197-216
- Heichel, G. H.; Musgrave, R. B., 1969
Varietal differences in net photosynthesis of *Zea mays* L.
Crop Science 9:483-486
- Hesketh, J. D.; Chase, S. S.; Nanda, D. K., 1969
Environmental and genetic modification of leaf number in maize, sorghum and Hungarian millet
Crop Science 9:460-43
- Hillel, D.; Guron, Y., 1973
Relation between evapotranspiration and maize yield
Water Resources Research 7:743-748
- Hodges, D. M.; Hamilton, R. I.; Charest, C., 1994
A chilling resistance test for inbred maize lines
Canadian Journal of Plant Science 74:687-691
- Holland, C.; Kezar, W., 1990
Pioneer Forage Manual : A nutritional guide
Pioneer Hi-Bred International Inc. Des Moines, IA
- Hope, H. S.; White, R. P.; Dwyer, L. M.; Maamari, R.; Seguin, S.; Hamilton, R. I., 1992
Low temperature emergence potential of short season corn hybrids grown under controlled environment and plot conditions
Canadian Journal of Plant Science 72:83-91
- Huber, J. T.; Thomas, J. W.; Emery, R. S., 1968
Response of lactating cows fed urea treated corn silage harvested at varying stages of maturity
Journal of Dairy Science 51:1806-1810

- Huber, J. T.; Graf, G.C.; Engel, R. W., 1965
Effect of maturity on nutritive value of corn silage for lactating cows
Journal of Dairy Science 48:1121-1123
- Hume, D. J.; Campbell, D. K. 1972
Accumulation and translocation of soluble solids in corn stalks
Canadian Journal of Plant Science 52:363-368
- Hunt, C. W.; Kezar, W.; Vinande, R., 1989
Yield and chemical composition and ruminal fermentability of corn whole plant, ears and stover as affected by maturity
Journal of Production Agriculture 2(4):357-361
- Hunt, C. W.; Kezar, W.; Vinande, R., 1992
Yield, chemical composition, and ruminal fermentability of corn whole plant, ear and stover as affected by hybrid
Journal of Production Agriculture 5:286-290
- Hunter, R. B.; Tollenaar, M.; Breuer, C. M., 1977
Effects of photoperiod and temperature on vegetative and reproductive growth of a maize (*Zea mays* L.) hybrid
Canadian Journal of Plant Science 57:1127-1133
- Hunter, R. B.; Kannenberg, L. W.; Gamble, E. E., 1970
Performance of five maize hybrids in varying plant populations and row widths
Agronomy Journal 62:255-256
- Hunter, R. B. 1986
Selecting hybrids for silage maize production: a Canadian experience. pp. 140-146
In: O. Dolstra and P. Miedema (eds.) Breeding of Silage Maize Proc. 13th Congress of the Maize and Sorghum Section of EUCARPIA Wageningen the Netherlands, 9-12 Sept. 1985
- Hunter, R. B.; Hunt, L. A.; Kannenberg, L. W., 1974
Photoperiod and temperature effects on corn
Canadian Journal of Plant Science 54:71-78
- Hunter, R. B. 1978
Selection and evaluation procedures for whole-plant corn silage
Canadian Journal of Plant Science 58:661-678
- Iremiren, G. O.; Milbourn, G. M., 1978
The growth of maize. I. Dry matter yields and quality components for silage
Journal of Agricultural Science (Cambridge) 90:569-577

- Irlbeck, N. A.; Russel, J. R.; Hallauer, A. R.; Buxton, D. R., 1993
Nutritive value and ensiling characteristics of maize stover as influenced by hybrid maturity and generation, plant density and harvest date
Animal Feed Science and Technology 41:51-64
- Jackson, M. B.; Drew, M.C., 1984
Effects of flooding on growth and metabolism of herbaceous plants. pp. 47-45
In: T.T. Kozlowski, editor, *Flooding and Plant Growth*. Academic Press, Inc. 345pp
- Jagush, K. T.; Hollard, M. G., 1974
Maize feeding studies with town-supply cows. II. Effect of variety on the production of maize grown for silage or grain
New Zealand Journal of Experimental Agriculture 2:67-73
- Jamieson, P. D.; Martin, R. J.; Francis, G. S., 1995
Drought influences on grain yield of barley, wheat and maize
New Zealand Journal of Crop and Horticultural Science 23:55-66
- Johnson, R. R.; McClure, K. E.; Johnson, L. J.; Klosterman, E. W.; Triplett, G. B. 1966
Corn Plant Maturity I. Changes in dry matter and protein distribution in corn plants
Agronomy Journal 58:151-153
- Johnson, R. R.; McClure, K. E., 1968
Corn plant maturity IV. Effects on digestibility of corn silage in sheep
Journal of Animal Science 27:535-540
- Jones, C. A.; Ritchie, J. T.; Kiniry, J. R.; Godwin, D. C., 1986
Subroutine structure. pp. 49-111
In: CA Jones and JR Kiniry (eds.). *CERES-Maize, a simulation model of maize growth and development*. Texas A and M Univ Press, College Station, Texas
- Jones, R. M.; Sandersson, M. A.; Read, J. C.; Lovell, A. C., 1995
Management of corn for silage production in South Central USA
Journal of Production Agriculture 8:175-180
- Jugenheimer, R. W., 1958
Hybrid maize breeding and seed production
FAO Agricultural Development Paper No. 62
- Kaiser, A. G., 1984
The influence of silage fermentation on animal production. p.106-135
In: TJ. Kempton, AG. Kaiser, TE. Trigg (eds.) *Silage in the 80's* PG. Print of Armidale

- Karlen, D. L.; Camp, C. R.; Zublena, J. P., 1985
 Plant density, distribution and fertilizer effects on yield and quality of irrigated corn silage
 Communication in Soil Science Plant Analysis 16(1):55-70
- Keeney, D. R., 1969
 Potassium boosts corn grain quality
 Better Crops 53:10-11
- Kerr, J. P.; McPherson, H. G.; Talbot, J. S., 1973
 Comparative evapotranspiration rates of lucerne, paspalum and maize
 Proc. First Australian Conference on Heat and Mass Transfer. Monash Univ. Melbourne. 23-25 May. Sections 3. pp. 1-8
- Kerr, J. P., 1982
 Environmental stress and crop productivity
 Technical Report No. 16. Plant Physiology Div., DSIR, Palmerston North, New Zealand
- Kerr, J. P., 1975
 The potential for maize production in New Zealand
 Proceedings Agronomy Society of New Zealand 5:65-69
- Kerr, J. P.; Clothier, B. E., 1975
 Modelling evapotranspiration of a maize crop
 Proceedings Agronomy Society of New Zealand 5:49-53
- Kezar, W. W., 1989
 What have we learned about corn silage in ten years? Reflections of Pioneer
 Pioneer Hi-Bred International Inc. Des Moines, IA
- Kiesselbach, T. A., 1949
 The structure and reproduction of corn
 Res. Bull. 161. Agricultural Research Station. Univ. Nebraska, College of Agriculture Lincoln, Nebraska
- Kiniry, J. R.; Keener, M.E., 1982
 An enzyme kinetic equation to estimate maize development rates
 Agronomy Journal 74:115-119
- Knapp, W. R.; Shaw Reid. W., 1981
 Interactions of hybrid maturity class, planting date, plant population and nitrogen fertilization on corn performance in New York
 Search: Agricultural Publication No. 21. 26pp
- Kramer, P. J., 1963
 Water stress and plant growth
 Agronomy Journal 55:31-35

- Lal, R.; Taylor, G. S., 1970
Drainage and nutrient effects in a field lysimeter study. II. Mineral uptake by corn
Soil Science Society of America Proceedings 34:245-248
- Lal, R.; Taylor, G. S., 1969
Drainage and nutrient effects in a field lysimeter study. I. Corn yield and soil conditions
Soil Science Society of America Proceedings 33:937-941
- Lambers, H., 1987
Does variation in photosynthetic rate explain variation in growth rate and yield
Netherlands Journal of Agricultural Science 35:505-519
- Larson, W. E.; Hanway, J. J., 1977
Corn production
In: G. F. Spargue, ed., Corn and corn improvement. Agronomy 18:625-699.
American Society of Agronomy, Madison, Wisconsin
- Larson, J. C.; Maranville, J. W., 1977
Alterations of yield, test weight and protein in lodged grain sorghum
Agronomy Journal 69:629-630
- Laude, H. H.; Pauli, A. W., 1956
Influence of lodging on yield and other characters in winter wheat
Agronomy Journal 48:452-455
- Leask, W. C.; Daynard, T. B., 1973
Dry matter yield, in vitro grain digestibility, percent protein, and moisture of corn stover following grain maturity
Canadian Journal of Plant Science 53:515-522
- Leopole, A. C.; Kriedemann, P. E. 1975
Plant growth and development
2nd ed. McGraw-Hill, New York
- Lewis, R. P. W., 1991
Meteorological glossary
Meteorological Office London-HMSO. 335pp
- Linton, R. W., 1975
Maize silage for dairy production-Description of a farm operation
Proceedings Agronomy Society of New Zealand 5:91-94
- Lucas, E. O.; Remison, S. U., 1984
Effect of population density on yield and dry matter partitioning in maize varieties in Nigeria
Indian Journal Agricultural Sciences 54:284-290

- Lucas, E. O., 1986
The effect of density and nitrogen fertilizer on the growth and yield of maize in Nigeria
Journal of Agricultural Science (Cambridge) 107:573-578
- Lundvall, J. P.; Buxton, D. R.; Hallauer, A. R.; George, J. R., 1994
Forage quality variation among maize inbreds: in vitro digestibility and cell-wall components
Crop Science 34:1672-1678
- Lusk, J. W., 1978
The use of preservatives in silage production. p. 201-232
In: M. E. McCullough (ed.) *Fermentation of silage-A Review*. Nat. Feed. Ingr. Assoc. Des Moines, IA
- Lutz, J. A.; Jones, G. D., 1969
Effect of corn hybrids, row spacing, and plant population on the yield of corn silage
Agronomy Journal 61:942-945
- Lutz, J. A.; Camper, H. M.; Jones, G. D., 1971
Row spacing and population effects on corn yields
Agronomy Journal 63:12-14
- Mallarino, A. P.; Webb, J. R.; Blackmer, A. M., 1991
Corn and soybean yields during 11 years of phosphorous and potassium fertilization on a high testing soil
Journal of Production Agriculture 4:312-317
- Mallarino, A. P.; Webb, J. R., 1995
Long-term evaluation of phosphorous and zinc interactions in corn J.
Journal of Production Agriculture 8(1):52-55
- Mallarino, A. P.; Blackmer, A. M., 1992
Comparison of methods for determining critical concentrations of soil test phosphorous for corn
Agronomy Journal 84:850-856
- McAllan, A. B.; Phipps, R. H., 1977
The effect of sample date and plant density on the carbohydrate content of forage maize and the changes that occur on ensiling
Journal of Agriculture Science (Cambridge) 89:589-597
- McCormick, S. J., 1983
Maize for grain
AgLink 1/5000/2/83:FPP 609. Media Services, MAF, Wellington, New Zealand

- McCormick, S. J., 1980
The effect of early season temperature on maize growth and its relation to grain yield
Proceedings Agronomy Society of New Zealand 10:31-33
- McCormick, S. J., 1971
The effects of sowing date on maize development and yields of silage and grain
Proceedings First Annual Conference Agronomy Society of New Zealand pp 51-66
- McCormick S. J., 1974
Early sowing of maize: effect on rate of development, growth, yield and optimum plant population
Proceedings Agronomy Society of New Zealand 4:90-93
- McCormick, S. J., 1979
The effect of seasonal variation in temperature on the yield of maize in the Waikato and Gisborne regions
Proceedings Agronomy Society of New Zealand 9:93-96
- McPherson, H. G.; Boyer, J. S., 1977
Regulation of grain yield by photosynthesis in maize subjected to a water deficiency
Agronomy Journal 69:714-718
- Meidema, P. 1982
The effects of low temperature on *Zea mays L*
Advances in Agronomy 35:93-128
- Meikle, R. W.; Treadway, T. R., 1981
A mathematical method for estimating soil temperatures in Canada
Soil Science 131:320-326
- Menalda, P. H.; Kerr, J. P., 1973
Silage maize production in the Manawatu
Proceedings Agronomy Society of New Zealand 3:47-55
- Miller, W. J.; Clifton, C. M., 1965
Relation of DM content in ensiled material and other factors to nutrient losses by seepage
Journal of Dairy Science 48:917-923
- Minson, D. J.; Cowan, T.; Havilah, E., 1993
Northern dairy feedbase 2001. 1. Summer pasture and crops
Tropical Grasslands 27:131-149

- Mock, J. J.; McNeill, M. J., 1979
Cold tolerance of maize inbred lines adapted to various latitudes in North America
Crop Science 19:239-242
- Mock, J. J.; Pearce, R. B., 1975
An ideotype of maize
Euphytica 24:613-623
- Montgomery, M. J.; Fribourg, H. A.; Overton, J. R.; Hopper, W. M., 1974
Effect of maturity of corn on silage quality and milk production
Journal of Dairy Science 57:98-702
- Moran, J. B. 1984
The nutritive value of maize silage grown under irrigation in Northern Victoria. pp409
In: T. J. Kempton, A. G. Kaiser and T. E. Trigg, Silage in the 80's. National Workshop Armidale NSW
- Murdock, J. T.; Stengel, P. J.; Doersch, R.E., 1962
How fertility and balance can affect corn production
Better Crops 46:16-21
- Nash, M. J., 1978
Crop conservation and storage in cool temperature climates
Pergamon Press. pp. 254-260
- Newton, S. D., 1984
Crop Production in New Zealand
Agronomy Department, Massey University, Palmerston North, New Zealand
- Nicholson, J. W. G.; Belanger, G.; Burgess, P. L., 1986
Comparison of silage from densely seeded and conventionally seeded corn for beef steers
Canadian Journal of Animal Science 66:431
- Noor, R. B. M.; Caviness, C. E., 1980
Influence of induced lodging in pod distribution and seed yield in soybeans
Agronomy Journal 72:904-906
- Oleson, B. T., 1994
World wheat production, utilisation and trade pp. 1-12 In: W. Bushuk and V.F. Rasper, *Wheat Production Properties and Quality*. Blackie and Professional, Wester Cleddens Road, Bishopbriggs, Glasglow G642NZ, U.K

- Otegui, M. E.; Nicolini, M. G.; Ruiz, R. A.; Dodds, P. A. 1995
Sowing date effects on grain yield components for different maize
genotypes
Agronomy Journal 87:29-33
- Owen, F. G., 1967
Factors affecting nutritive value of corn and sorghum silage
Journal of Dairy Science 50:404-416
- Pain, B. F., 1978
Nutritional requirements of forage maize. pp.87-116
In: *Forage maize* (eds.) E. S. Bunting, B. F. Pain, R. H. Phipps, J. M.
Wilkinson, R. E. Gunn. Agricultural Research Council, London, 1978
- Pendleton, J. W.; Egli, D. B., 1969
Potential yield of corn as affected by planting date
Agronomy Journal 61:70-71
- Perry, T. W.; Caldwell, D.M., 1969
Comparative nutritive value of silages made from high sugar male sterile
hybrid corn and regular starchy corn
Journal of Dairy Science 52:1119-1121
- Perry, T. W.; Rhykerd, C. L.; Holt, D. A.; Mayo, H. H., 1972
Effect of potassium fertilization on chemical characteristics on yield and
nutritive value of corn silage
Journal of Animal Science 34:642-646
- Phipps, R. H. 1975
A note on the effect of density and row width on the yield and quality of forage
maize
Journal of Agricultural Science Camb 84:567-569
- Phipps, R. H.; McAllan, A. B., 1984
Carbohydrates constituents and amino acid composition of maize silage grown
on commercial farms in the UK
Maydica 27-38
- Phipps, R. H.; Fulford, R. J.; Weller, R. F., 1981
The effect of maize silage grain content on live-weight gain of beef
cattle
Maydica 26:93-99
- Phipps, R. H.; Weller, R. F., 1979
The development of plant components and their effects on the composition of
fresh and ensiled forage maize. 1. The accumulation of dry matter, chemical
composition and nutritive value of fresh maize
Journal of Agricultural Science (Cambridge) 92:471-483

- Phipps, R. H. 1980
 A review of the carbohydrate content and digestibility value of forage maize grown in cool climate conditions of the UK and their relevance to animal production. pp. 291-317
 In: WG. Pollmer and RH. Phipps (ed.). Improvement of quality traits of maize for grain and silage use. Martinus Nijhoff, The Hague, Boston, London
- Pierre, W. H.; Dumenil, L.; Jolley, V. D.; Webb, J. R.; Shrader W. D. 1977
 Relationship between corn yield, expressed as a percentage of maximum and the N percentage in the grain. I. Various N-rate experiments
 Agronomy Journal 69:215-220
- Pinter, L., 1986
 Ideal type of forage maize hybrid. pp.123-130
 In: O. Dolstra and P. Miedema (eds.) Breeding of silage maize Proc. 13th congress on the maize and sorghum section of Eucarpia Wageningen, The Netherlands. 9-12 Sept. 1985. Pudoc, Wageningen, The Netherlands
- Pinter, L.; Alfoldi, Z.; Burucs, Z.; Paldi, E., 1994
 Feed value of forage maize hybrids varying in tolerance to plant density
 Agronomy Journal 86:799-804
- Pinter, L.; Schmidt, J.; Joyza, S. ; Szabo, J.; Kelemen, G. 1990
 Effect of plant density on the feed value of forage maize
 Maydica 35:73-79
- Pinter, L.; Hunter, R. B.; Szabo, J., 1986
 Near infrared technique as a tool for investigating corn silage quality
 Maydica 31:295-305
- Poethig, R. S., 1994
 The maize shoot. pp.11-16
 In: M. Freeling, V. Walbot (eds.) The Maize Handbook, Springer-Verlag, NY Inc
- Pollmer, W. G., 1980
 The improvement of quality traits of maize for grain and silage use as an international and interdisciplinary task. p.9-14
 In: eds. WG. Pollmer, RH. Phipps. Improvement of quality traits of maize for grain and silage use. Mantinus. Nijhoff Publishers
- Potter, J. R.; Jones, J. W., 1977
 Leaf area partitioning as an important factor in growth
 Plant Physiology 59:10-14
- Quattar, S.; Jones, R. J.; Crookston, R. K.; Kajeiou, M., 1987
 Effect of drought on water relations of developing maize kernels
 Crop Science 27:730-735

- Rehm, G. W.; Sorensen, R. C.; Wiese, R. A., 1981
Application of phosphorous, potassium and zinc to corn grown for grain or silage: Early growth and yield
Soil Science Society America Journal 45:523-528
- Rench, W. E.; Shaw, R. H., 1971
Blacklayer development in corn
Agronomy Journal 63:303-305
- Ritchie, S. W.; Hanway, J. J., 1982
How a corn plant develops
Iowa State University Cooperative Extension Service Special Report No. 48
- Robins, J. S.; Domingo, C. E., 1953
Some effects of severe soil moisture deficits at specific growth stages in corn
Agronomy Journal 45:618-621
- Robinson, D. L.; Murphy, L. S., 1972
Influence of nitrogen, phosphorous and plant population on yield and quality of forage corn
Agronomy Journal 64:349-351
- Rossmann, E. C.; Cook, R. L., 1966
Soil preparation and date, rate and pattern of planting
In: W.H. Pierre, S.A. Aldrich and W.P. Martin. (eds.) Advances in corn production, principles and practices. pp. 53-101. Iowa State Univ. Press. Ames
- Roth, G. W.; Ashmawy, F.; Rosenberger, J. L.; Fox, R. H.; Piekelek, W. P., 1995
Effect of harvest method and feed value on the economic optimum nitrogen rate for corn
Communication in Soil Science Plant Analysis 26(7 & 8):1009-1021
- Roth, L. S.; Marten, G. C.; Compton, W. A.; Stuthman, D. D., 1970
Genetic variation of quality traits in maize forage
Crop Science 10:365-367
- Roth, G.; Undersander, D., 1995
Corn silage production, management and feeding
In: M. Allen et. al., contributors. ASA, CSSA, SSSA 42pp
- Roth, L. D.; Klopfenstein, T.; Hoegemeyer, T.; Nielsen, M. K.; Bartle, S. J., 1987
Relation of corn grain yield to forage quality
Journal of Animal Science 65(Suppl. 1):143
- Roth, G. W., 1994
Hybrid quality and yield differences for corn silage in Pennsylvania
Journal of Production Agriculture 7(1):50-54

- Russel, W. A. 1984
Further studies on the response of maize inbred lines to N fertilizer
Maydica. 29:141-150
- Russel, W. A., 1991
Genetic improvement of maize yields
Advances in Agronomy 46:245-298
- Russel, W. A., 1974
Comparative performance for maize hybrids representing different eras
of maize breeding
Proceeding Annual Corn and Sorghum Reseach Conference 29:81-101
- Rutger, J. N.; Crowder, L. V., 1967
Effect of population and row width on corn silage yields
Agronomy Journal 59:475-476
- Sayre, J. D., 1948
Mineral accumulation in corn
Plant Physiology. Vol 23. No. 3:267-281
- Sayre, J. D., 1955
Mineral nutrition of corn. pp. 293-314
In: G.F. Sprague (ed.) Corn and Corn Improvement. Academic Press Inc
NY
- Schaefer, G., 1984
Production of maize for silage. pp. 37-53
In: T. J. Kempton, A. G. Kaiser, T. E. Trigg (eds.) Silage in the 80's
Proc. Nat'l. Workshop, Armidale, NSW Australia 8-9 August 1984
- Schneider, E. C.; Gupta, S. C., 1985
Corn emergence as influenced by soil temperature, matric potential and
aggregate size distribution
Soil Science Society of America Journal 49:415-422
- Schrimpf, K., 1966
Maize cultivation and fertilization
Series of monograph on tropical and subtropical crops. RUHR-
STICKSTOFF AG, BOCHUM, WestGermany. 172pp
- Schulz, F. A.; Bateman, D. F., 1968
Temperature responses of seeds during early phases of germination and
its relation to injury by *Rhizoctonia solani*
Phytopathology. 59:353-355

- Schussler, J. R.; Westgate, M. E., 1994
 Increasing assimilate reserves does not prevent kernel abortion at low water potential in maize
 Crop Science 34:1569-1576
- Schussler, J. R.; Westgate, M. E., 1991
 Maize kernel set at low water potential. II. Sensitivity to reduced assimilates at pollination
 Crop Science 31:1196-1203
- Schwab, G. O.; Taylor, G. S.; Fouss, J. F.; Stibbe, E. 1966
 Crop response from tile and surface drainage
 Soil Science Society of America Journal 30:634-637
- Segeta, V., 1960
 Cold resistance of germinating maize
 Rostlinna Vyroba 33:307-318
- Shaw, R. H., 1977
 Climatic requirements. pp.591-623
 In: G.F. Sprague (editor), Corn and Corn Improvement. No. 18. ASA Inc
 Madison, Wisconsin, USA
- Shaw, R. H., 1974
 A weighted moisture-stress index for corn in Iowa
 Iowa State Journal Research 49:101-114
- Shaw, R. H.; Thom. H. C. S., 1951
 On the phenology of field corn
 Agronomy Journal 43:541-546
- Shaw, R. H., 1988
 Climate requirement
 In: G. F. Sprague, J. W. Dudley (eds.). Corn and corn improvement. 3rd ed.
 ASA. Agron. Monogr. Ser. No. 18, ASA, CSSA, SSSA, Madison, WI. pp.609-638
- Shaw, R. H.; Loomis, W. E., 1950
 Basis for predicting corn yields
 Plant Physiology 25:225-244.
- Shaw, R. H., 1955
 Climatic requirement. pp.315-341
 In: G. F. Sprague (ed.). Corn and corn improvement. Academic Press.
 Inc. Publishers

- Smith, B. A. J., 1982
Maize for silage
AgLink 1/3000/8/82:FPP 666. Media Services, MAF, Wellington, New Zealand
- Smith, L. H.; Otto, H. J.; Brooking, N., 1963
Silage production and preservation
Minnesota, Agric. Ext. Serv. Bull. 308pp
- Smith, C. S.; Kannenberg, L. W.; Hunter, R. B., 1978
Development of maize gene pools at high plant densities. II. Effect on grain yield
Canadian Journal of Plant Science 58:101-105
- Snyder, F. W.; Carlson, G. E., 1984
Selecting for partitioning of photosynthetic products in crops. pp. 47-69
In: N.C. Brady, editor, Advances in Agronomy. Vol. 37. Academic Press Inc
- Sprague, G. F., 1955
Corn breeding. pp.221-283
In: G. F. Sprague (ed.) Corn and Corn Improvement. Academic Press Inc
- St. Pierre, N. R.; Bouchard, R; St. Laurent, G.J.; Roy, G. L.; Vinet, C., 1987
Performance of lactating dairy cows feed silage from corn of varying maturities
Journal of Dairy Science 70:108-115
- St. Pierre, N. R.; Bouchard, R; St. Laurent, G. J.; Roy, G. L., 1983
Effect of stage of maturity and frost on nutritive value of corn silage for lactating dairy cows
Journal of Dairy Science 66:1466-1473
- Stake, P. E.; Owens, M. J.; Schingoethe, D. J.; Voelker, H. H., 1973
Comparative feeding value of high sugar male sterile and regular dent corn silages
Journal of Dairy Science 56:1439-1444
- Steele, K. W., 1983
Efficient utilization of soil and fertilizer N to optimise maize grain yield
Proceeding Agronomy Society of New Zealand 13:33-38
- Steele, K. W.; Cooper, D. M.; Dyson, C. B., 1982
Estimating nitrogen fertilizer requirements in maize grain production. 2. Estimates based on ear leaf and grain nitrogen concentrations
New Zealand Journal of Agricultural Research 25:207-210.
- Steele, K. W.; McCormick, S. J.; Percival, N. S.; Brown, N. S., 1981
Nitrogen, phosphorous, potassium, magnesium and sulphur requirements for maize grain production
New Zealand Journal of Experimental Agriculture 9:243-249

- Steele, K. W., 1985
Efficient utilization of soil and fertiliser N to optimize maize grain yield
Proceeding Agronomy Society of New Zealand 13:33-38
- Steele, K. W., 1981
Maize fertilizers. Estimating nitrogen fertilizer requirements
New Zealand AgLink FPP602. Ministry of Agriculture and Fisheries
- Steele, K. W., 1985
Fertilizer management for grain maize. pp. 29-26
In: H. A. Eagles, G. S. Wratt (eds.) Maize-management to market. Lincoln, NZ.
Special Publication No.4, Agronomy Society of New Zealand
- Stevenson, J. C.; Goodman, M. M., 1972
Ecology of exotic races of maize. 1. Leaf number and tillering of 16 races under
four temperature and two photoperiods
Crop Science 12:864-868
- Stewart, J. I.; Hagan, R. M., 1973
Functions to predict effects of crop water deficits
Journal Irrigation and Drainage Division. American Society of Civil Engineers
99:421-439
- Stinson, H. T., Jr.; Moss, D. N., 1960
Some effect of shade upon corn hybrids tolerant and intolerant of dense
planting
Agronomy Journal 52:482-484
- Struik, P. C.; Deinum, B., 1982
Effect of light intensity after flowering on the productivity and quality of
silage maize
Netherlands Journal of Agricultural Science 30:297-316
- Struik, P. C., 1984
An ideotype of forage maize for north-west Europe
Netherlands Journal of Agricultural Science 32:145-147 (Synopsis)
- Struik, P. C.; Deinum, B.; Hoefsloot, M. M. P., 1985
Effects of temperature during different stages of development on growth and
digestibility of forage maize
Netherlands Journal of Agricultural Science 33:405-420
- Taylor, A. O. 1975
Maize and sorghum silage-USA and UK Experience
Proceeding Agronomy Society of New Zealand 5:75-78

- Tetio-Kagho, F.; Gardner, F. P., 1988
Responses of maize to plant density. I. Canopy development, light relationships, and vegetative growth
Agronomy Journal 80:930-935
- Thom, E. R.; Watkin, B. R., 1978
Effect of rate and time of fertilizer nitrogen application on total plant shoot and root yields of maize
New Zealand Journal of Experimental Agriculture. 6:29-38
- Thom, E. R.; Dorofaeff, F. D.; Dyson, C. B., 1981
Effect of plant population and time of harvest on yield and quality of maize grown for silage. I. Yield and chemical composition, and sampling procedures for large areas
New Zealand Journal of Agricultural Research 24:285-292
- Thom, E. R. 1974
Effects of nitrogen fertilizer on the growth, development and yield of maize (*Zea mays* L.)
Master in Agricultural Science Thesis, Massey University
- Thom, E. R., 1977
The effect of plant population and time of harvest on growth of hybrid and non-hybrid maize
Proceeding Agronomy Society of New Zealand 7:75-80
- Thomison, P. R.; Jordan, D. M., 1995
Plant population effects on corn hybrids differing in ear growth habit and prolificacy
Journal of Production Agriculture 8(3):394-400
- Thomson, A. J.; Rogers, H. H., 1968
Yield and quality components in maize grown for silage
Journal of Agricultural Science (Cambridge) 71:393-403
- Tollenaar, M.; Daynard, T. B.; Hunter, R. B., 1979
Effect of temperature on rate of leaf appearance and flowering of maize
Crop Science 19:36-366
- Tollenaar, M., 1989
Response of dry matter accumulation in maize to temperature. I. Dry matter partitioning
Crop Science 29:1239-1246
- Tollenaar, M.; Daynard, T. B. 1978
Effect of defoliation on kernel development in maize
Canadian Journal of Plant Science 58:207-212

- Tollenaar, M.; McCullough, D. E.; Dwyer, L. M., 1994
Physiological basis of the genetic improvement of corn. pp. 183-237
In: G.A. Slafer (ed.). Genetic Improvement of Field Crops. Marcel Dekker Inc.
Madison Ave., New York. 470pp
- Tollenaar, M., 1992
Is low plant density a stress in maize?
Maydica 37:305-311
- Tollenaar, M.; Hunter, R. B., 1983
A photoperiod and temperature sensitive period for leaf number of maize
Crop Science 23:457-460
- Tollenaar, M., 1989
Genetic improvement in grain yield of commercial maize hybrids grown in
Ontario from 1959 to 1988
Crop Science 29:1365-1371
- Tollenaar, M., 1977
Sink-source relationship during development in maize, A Review
Maydica 22:49-75
- Toy, T. J.; Kuhaida, A. J. Jr.; Munson, B. E., 1978
The prediction of mean monthly soil temperature from mean monthly air
temperature
Soil Science 126:96-104
- Toy, T. J.; Kuhaida, A. J. Jr., 1979
A mathematical method for estimating soil temperatures
Soil Science 129:226-326
- Trappeniers, G.; Ledent, J. F.; Fayt, O.; Nijs, A., 1992
Effects of simulated hail damage on the yield of forage maize
Journal of Agronomy and Crop Science 168:13-19
- Tsai, C. Y.; Dewikat, I.; Huber, D. M.; Warren, H. L., 1992
Interrelationship of nitrogen nutrition with maize (*Zea mays* L.) grain yield,
nitrogen use efficiency and grain quality
Journal of Science in Food and Agriculture 58:1-8
- Tsai, C. Y.; Huber, D. M.; Glover, D. V.; Warren, H. L., 1984
Relationship of N deposition to grain yield and N response of three maize
hybrids
Crop Science 24:277-281
- U. S. D. A., 1971
Nutrient requirements of dairy cattle

- Ulyatt, M. J.; Fenessy, P. F.; Rattray, P. V.; Jagusch, K. T., 1980
The nutritive value of supplements. p. 157-184
In: K. R. Drew, P. F. Fenessy (eds.) Supplementary Feeding-a guide to the production of feeding supplements. A New Zealand Society of Animal Production Publication
- Underwood, R. A., 1985
Maize growing practices. p.25-29
In: Maize: management to market (eds.) H. A. Eagles and G. S. Wratt. Special Publication Agronomy Society of New Zealand
- van Dobben, W. H., 1962
Influence of temperature and light conditions on dry-matter distribution, development rate and yield in arable crops
Netherlands Journal of Agricultural Science 10:377-389 Special Issue
- van Royen, W., 1954
The agricultural resources of the world
USDA. Bureau of Ag. Economics and Univ. of Maryland. New York, Prentice-Hall
- van Arkel H., 1980
The forage and grain yield of cold-tolerant sorghum and maize as affected by the time of planting in the highlands of Kenya
Netherlands Journal of Agricultural Science 28:63-77
- Van Eijnatten, C. L. M., 1963
A study of the the development of two varieties of maize at Ibadan
Nigerian Journal of Agricultural Science 61:65-72
- Vandersall, J. H.; Hemken, R. W.; Clark, N.Z., 1962
Yield and feeding value of corn silage as affected by nitrogen fertilization
Journal of Animal Science 21:1038 (Abst.)
- Vattikonda, M. R.; Hunter, R. B., 1983
Comparison of grain yield and whole-plant silage production of recommended corn hybrids
Canadian Journal of Plant Science 63:601-609
- Vetter, R. L.; von Glan, K. N., 1978
Abnormal silages and silage related disease problems. pp. 291-293 In: M. E. McCullough (ed.) Fermentation of silage-A Review. Nat. Feed. Ingr. Assoc. Des Moines, IA
- Voldeng, H. D.; Blackman, G. E., 1975
Interactions between genotype and density on the yield components of *Zea mays* L. II. Grain production
Journal of Agricultural Science (Cambridge) 84:61-74

- Waghorn, G. C.; Wilson, G. F., 1974
Nutritive characteristics of maize silage and maize silage/grass rations for cattle
Proceeding New Zealand Society of Animal Production 34:78 (Summary)
- Waldern, D. E., 1972
Effects of supplemental hay on consumption of low and medium dry matter corn silage by high producing dairy cows
Canadian Journal of Animal Science 52:491-495
- Wallace, A. R.; Davies, D. J., 1976
Maize densities for forage production in Canterbury
Proceeding Agronomy Society of New Zealand 6:37-42
- Warrington, I. J.; Kanemasu, E.T., 1983c
Corn growth response to temperature and photoperiod. III. Leaf number
Agronomy Journal 75:762-766
- Warrington, I. J.; Kanemasu, E. T., 1983a
Corn growth response to temperature and photoperiod. I. Seedling emergence, tassel initiation and anthesis
Agronomy Journal 75:749-54
- Warrington, I. J.; Kanemasu, E. T., 1983b
Corn growth response to temperature and photoperiod. II. Leaf-initiation and leaf appearance rates
Agronomy Journal 75:755-761
- Watson, D. J., 1952
The physiological basis of variation in yield
Advances in Agronomy 4:101-145
- Watson, D. J., 1958
The dependence of net assimilation rate on leaf-area index
Annals of Botany. 22(85):37-54
- Weaver, D. E.; Coppock, C. C.; Lake, G. B.; Everett, R. W. 1978
Effect of maturation on composition and in vitro dry matter digestibility of corn plant parts
Journal of Dairy Science 61:1782-1788
- Webb, J. R.; Mallarino, A. P.; Blackmer, A. M., 1992
Effects of residual and annually applied phosphorous on soil test values and yields of corn and soybean
Journal of Production Agriculture 5:148-152

- Weber, C.R.; Fehr, W. R., 1966
Seed yield losses from lodging and combine harvesting in soybeans
Agronomy Journal 58:287-289
- Weibel, R. O.; Pendleton, J. W., 1964
Effect of artificial lodging on winter wheat grain yield and quality
Agronomy Journal 56:487-488
- Westgate, M. E.; Boyer, J. S., 1986a
Silk and pollen with potentials in maize
Crop Science 26:947-951
- Westgate, M. E.; Boyer, J. S., 1986b
Reproduction at low silk and pollen water potentials in maize
Crop Science 26:951-956
- White, R. P. 1976
Effect of plant population of forage corn yields and maturity on Prince
Edward Island
Canadian Journal of Plant Science 56:71-77
- White, R. P.; Winter, K. A.; Kunelius, H. T., 1976
Yield and quality of silage corn as affected by frost and harvest at
Canadian Journal of Plant Science 56:481-486
- Wiersma, D. W.; Carter, P. R.; Albrecht, K. A.; Coors, J. G., 1993
Kernel milkline stage and corn forage yield, quality and DM content
Journal of Production Agriculture 6:94-99
- Wilkinson, J. M.; Penning Ines, M.; Osbourn, D. T., 1978
Effect of stage of harvest and fitness of chopping on the voluntary intake
and digestibility of maize silage by young beef cattle
Animal Production 26:143-150
- Wilkinson, J. M., 1978
The ensiling of forage maize: Effects on composition and nutritive value.
pp. 201-237
In: E. S. Bunting et. al. (ed.) *Forage maize:production and utilization.*
Agric. Res. Council, London
- Wilkinson, J. M., 1985
Beef production from silage and other conserved forages
Longman New York-London 140pp
- Willey, R. W., 1982
Plant population and crop yield. pp. 201-207
In: M. Rechcigl, Jr. (ed.) *Handbook of agricultural productivity Vol. I.*
CRC Press, Inc. Florida

- Williams, W. A.; Loomis, R. S.; Lepley, C. R., 1965
Vegetative growth of corn as affected by population density. II.
Components of growth, net assimilation rate and leaf area index
Crop Science 5:215-219
- Wilson, D. R.; Brooking, I. R.; Johnstone, J. V., 1991
Potential and risks of maize grain and silage production in Canterbury.
II. analysis of climatic risk
Proceeding Agronomy Society of New Zealand 21:33-35
- Wilson, J. H.; Allison, J. C. S., 1978
Production and distribution of fry matter in maize following changes in
plant population after flowering
Annals of Applied Biology 90:121-126
- Wilson, D. R.; Johnstone, J. V.; Salinger, M. J., 1994
Maize production potential and climatic risk in the south island of New
Zealand
New Zealand Journal of Crop and Horticultural Science. 22:321-334
- Wolf, D. R.; Coors, J.G.; Albrecht, K. A.; Undersander, D. J.; Carter, P. R. 1993b
Agronomic evaluations of maize genotypes selected for extreme fibre
concentrations
Crop Science 33:1359-1365
- Wolf, D. R.; Coors, J. G.; Albrecht, K. A.; Undersander, D. J.; Carter, P.R., 1993a
Forage quality of maize genotypes selected for extreme fibre
concentrations
Crop Science 33:1353-1359
- Woods, S. J.; Swearingin, M. L., 1977
Influence of simulated early lodging upon soybean yield and its
components
Agronomy Journal 69:239-242
- Yamaguchi, J., 1974
Varietal traits limiting the grain yield of tropical maize. I. The growth and yield
of tall and short varieties
Soil Science Plant Nutrition 20:145-154
- Zimmer, E., 1971
Factors affecting fermentation in silo. pp58-78
In: Technical papers presented at Int. Silage Res. Conf. National Silo Assoc.,
Cedar Falls, Iowa
- Zimmer, E., 1971
Kriterien für die Beurteilung des Futterwertes von Silomais und ccm.5.
KWS Mais-Kolloquium, Einbeck. p.8-19

Zimmer, E.; Wermke, M., 1986

Improving the nutritive value of maize. 91-100pp

In: O. Dolstra and P. Miedema (eds.) Breeding of Silage Maize Proc.
13th Congress of the Maize and Sorghum Section of EUCARPIA
Wageningen the Netherlands, 9-12 Sept. 1985

Zinselmeier, C. J.; Schussler, J. R.; Westgate, M. E.; Jones, R. J., 1991

Effect of light environment and genotype on seed set at low water
potential in maize. pp.136

In: Agronomy Abstracts, ASA, Madison, WI

Appendix 1. Daily temperature data with the corresponding heat unit for the 1994/95 maize growing season at Palmerston North.
Source: AgResearch Grasslands, Palmerston North.

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
4 Nov 94	17.60	10.00	13.80	07.80
5	18.80	10.50	14.65	08.65
6	22.50	08.30	15.40	09.40
7	21.90	14.00	17.95	11.95
8	16.00	12.60	14.30	08.30
9	16.70	11.30	14.00	08.00
10	15.00	09.00	12.00	06.00
11	16.80	11.00	13.90	07.90
12	16.90	11.00	13.95	07.95
13	17.60	10.40	14.00	08.00
14	18.80	13.10	15.95	09.95
15	16.40	14.10	15.25	09.25
16	14.30	12.00	13.15	07.15
17	14.40	08.40	11.40	05.40
18	16.30	11.60	13.95	07.95
19	14.60	08.90	11.75	05.75
20	14.20	05.40	09.80	03.80
21	18.00	08.70	13.35	07.35
22	18.80	12.00	15.40	09.40
23	15.20	10.30	12.75	06.75
24	17.20	11.40	14.30	08.30
25	19.30	08.50	13.90	07.90
26	18.00	08.80	13.40	07.40
27	17.70	10.80	14.25	08.25
28	18.40	08.00	13.20	07.20
29	16.40	12.30	14.35	08.35
30	19.40	12.00	15.70	09.70
Mean	17.30	10.53	13.92	07.92

Continuation of Appendix 1

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
1 Dec 94	19.00	13.00	16.00	10.00
2	21.70	11.50	16.60	10.60
3	21.20	12.40	16.80	10.80
4	18.80	12.30	15.55	09.55
5	17.70	06.70	12.20	06.20
6	20.50	10.40	15.45	09.45
7	20.40	07.30	13.85	07.85
8	20.00	09.70	14.85	08.85
9	20.20	14.10	17.15	11.15
10	19.70	13.80	16.75	10.75
11	19.30	12.20	15.75	09.75
12	19.10	13.40	16.25	10.25
13	20.00	12.00	16.00	10.00
14	22.70	11.20	16.95	10.95
15	21.00	07.40	14.20	08.20
16	23.10	12.80	17.95	11.95
17	24.80	14.30	19.55	13.55
18	24.00	10.80	17.40	11.40
19	20.80	11.70	16.25	10.25
20	19.50	13.90	16.70	10.70
21	19.90	06.10	13.00	07.00
22	19.00	11.60	15.30	09.30
23	17.60	07.50	12.55	06.55
24	16.60	07.60	12.10	06.10
25	17.60	11.00	14.30	08.30
26	19.80	10.80	15.30	09.30
27	23.10	08.00	15.55	09.55
28	19.10	13.70	16.40	10.40
29	24.80	16.00	20.40	14.40
30	25.00	14.70	19.85	13.85
31	19.10	12.10	15.60	09.60
Mean	20.49	11.29	15.89	09.89

Continuation of Appendix 1.

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
1 Jan95	20.50	12.90	16.70	10.70
2	20.20	08.60	14.40	08.40
3	17.80	12.80	15.30	09.30
4	17.80	03.90	10.85	04.85
5	18.90	04.60	11.75	05.75
6	19.50	10.30	14.90	08.90
7	20.50	11.10	15.80	09.80
8	23.20	10.50	16.85	10.85
9	18.30	14.00	16.15	10.15
10	22.00	12.50	17.25	11.25
11	18.80	12.00	15.40	09.40
12	21.40	11.00	16.20	10.20
13	24.50	09.00	16.75	10.75
14	25.20	09.70	17.45	11.45
15	23.60	13.60	18.60	12.60
16	24.90	11.00	17.95	11.95
17	25.70	14.10	19.90	13.90
18	26.90	16.30	21.60	15.60
19	27.70	15.80	21.75	15.75
20	20.40	14.40	17.40	11.40
21	27.30	13.50	20.40	14.40
22	27.00	14.50	20.75	14.75
23	24.10	15.30	19.70	13.70
24	24.20	16.00	20.10	14.10
25	24.80	15.30	20.05	14.05
26	24.00	15.90	19.95	13.95
27	25.90	17.50	21.70	15.70
28	19.40	13.40	16.40	10.40
29	25.20	10.80	18.00	12.00
30	24.00	14.60	19.30	13.30
31	25.40	14.60	20.00	14.00
Mean	22.87	12.56	17.72	11.72

Continuation of Appendix 1.

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
1Feb95	28.90	13.00	20.95	14.95
2	18.30	16.70	17.50	11.50
3	21.70	13.30	17.50	11.50
4	20.40	16.60	18.50	12.50
5	24.20	15.00	19.60	13.60
6	21.30	13.90	17.60	11.60
7	25.40	13.00	19.20	13.20
8	24.30	17.40	20.85	14.85
9	23.40	14.80	19.10	13.10
10	23.50	16.30	19.90	13.90
11	23.90	17.00	20.45	14.45
12	19.60	14.50	17.05	11.05
13	21.60	14.50	18.05	12.05
14	22.40	14.20	18.30	12.30
15	24.90	13.00	18.95	12.95
16	24.60	13.50	19.05	13.05
17	26.40	12.00	19.20	13.20
18	24.50	12.60	18.55	12.55
19	22.10	10.70	16.40	10.40
20	24.00	15.60	19.80	13.80
21	20.00	13.90	16.95	10.95
22	24.00	14.60	19.30	13.30
23	26.20	16.80	21.50	15.50
24	23.60	15.30	19.45	13.45
25	22.40	15.30	18.85	12.85
26	25.60	11.80	18.70	12.70
27	23.50	15.10	19.30	13.30
28	21.20	14.50	17.85	11.85
Mean	23.28	14.46	18.87	12.87

Continuation of Appendix 1.

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
1March96	19.20	15.20	17.20	11.20
2	20.00	11.80	15.90	09.90
3	16.90	12.70	14.80	8.80
4	22.70	14.20	18.45	12.45
5	22.40	11.50	16.95	10.95
6	22.10	07.70	14.90	08.90
7	24.00	11.60	17.80	11.80
8	23.50	10.80	17.15	11.15
9	22.10	14.70	18.40	12.40
10	26.50	12.50	19.50	13.50
11	19.90	14.90	17.40	11.40
12	20.10	12.90	16.50	10.50
13	25.80	15.10	20.45	14.45
14	18.40	13.40	15.90	09.90
15	20.30	11.80	16.05	10.05
16	17.90	12.10	15.00	09.00
17	16.40	09.00	12.70	06.70
18	18.40	06.30	12.35	06.35
19	19.90	11.60	15.75	09.75
20	19.70	13.50	16.60	10.60
21	20.00	13.20	16.60	10.60
22	20.80	14.00	17.40	11.40
23	21.00	15.70	18.35	12.35
24	22.00	16.10	19.05	13.05
25	22.00	12.90	17.45	11.45
26	19.40	13.80	16.60	10.60
27	21.50	13.70	17.60	11.60
28	22.70	16.00	19.35	13.35
29	23.70	13.70	18.70	12.70
30	21.40	16.10	18.75	12.75
31	22.10	16.20	19.15	13.15
Mean	21.06	13.05	17.06	11.06

Continuation of Appendix 1.

Date	Max. Temp.	Min.Temp.	Mean Temp	Heat Unit
1 April 95	21.90	15.10	18.50	12.50
2	17.70	14.40	16.05	10.05
3	23.40	12.60	18.00	12.00
4	18.50	15.00	16.75	10.75
5	20.00	14.90	17.45	11.45
6	25.30	16.10	20.70	14.70
7	23.30	17.50	20.40	14.40
8	18.30	16.70	17.50	11.50
9	19.30	15.90	17.60	11.60
10	22.20	13.60	17.90	11.90
11	23.40	11.70	17.55	11.55
12	19.20	13.20	16.20	10.20
13	19.40	10.90	15.15	09.15
14	18.40	07.60	13.00	07.00
15	17.50	09.60	13.55	07.55
16	17.60	06.70	12.15	06.15
17	17.80	10.50	14.15	08.15
18	19.40	11.70	15.55	09.55
19	21.60	09.20	15.40	09.40
20	23.50	09.60	16.55	10.55
21	19.10	14.90	17.00	11.00
22	19.10	14.70	16.90	10.90
23	17.50	13.50	15.50	09.50
24	18.90	13.00	15.95	09.95
25	21.10	14.30	17.70	11.70
26	22.60	13.70	18.15	12.15
27	19.00	11.50	15.25	09.25
28	15.10	11.00	13.05	07.05
29	13.40	06.00	09.70	03.70
30	16.10	0.80	08.45	02.45
Mean	19.65	12.20	15.93	09.93

Appendix 2. Rainfall data for the 1994/95 maize growing season at Palmerston North. Source: AgResearch Grasslands, Palm. North

Date	Rainfall	Date	Rainfall	Date	Rainfall
1Nov94	5.00 mm	1Dec94		1Jan95	
2		2		2	1.20
3		3		3	0.60
4		4		4	
5		5		5	
6	6.00	6		6	
7	24.70	7		7	
8	32.60	8		8	5.70
9	7.70	9		9	10.80
10	0.80	10	3.50	10	
11		11		11	
12		12		12	
13		13	0.50	13	
14	32.50	14		14	
15	43.60	15		15	
16	11.00	16		16	
17		17		17	0.60
18	0.80	18		18	
19		19		19	
20	2.00	20	0.30	20	
21	12.80	21	10.10	21	
22	0.20	22	0.90	22	
23		23		23	
24		24	5.90	24	
25		25		25	
26		26		26	1.20
27		27		27	33.20
28		28	7.90	28	
28		29		29	0.20
30		30	16.40	30	
		31		31	
Total	179.70	Total	45.50	Total	53.50

Continuation of Appendix 2.

Date	Rainfall	Date	Rainfall	Date	Rainfall
1Feb95		1Mar95	0.30	1Apr95	3.80
2	4.50	2		2	0.80
3	0.90	3	5.90	3	
4		4		4	2.10
5	0.60	5		5	0.70
6		6		6	
7		7		7	2.60
8		8		8	12.00
9		9		9	7.50
10		10	5.10	10	3.30
11		11		11	31.60
12		12	20.40	12	
13		13	7.00	13	
14		14		14	
15		15	25.30	15	
16		16	7.80	16	
17		17	1.10	17	
18		18	1.10	18	
19		19	5.20	19	
20	16.70	20	24.00	20	5.60
21	3.80	21	1.70	21	3.00
22	2.80	22	2.50	22	6.10
23	26.30	23		23	
24	2.30	24	5.90	24	0.40
25		25		25	
26		26	7.70	26	24.10
27		27		27	
28		28		28	
28		29	19.80	29	
30		30	0.40	30	0.10
		31	7.10	31	
Total	57.90	Total	142.40	Total	103.70