AGRONOMIC EVALUATION OF TALL FESCUE (*FESTUCA ARUNDINACEA* SCHREB.) GERMPLASM

by

© Marcelo Renato Alves de Araujo

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Short title

AGRONOMIC EVALUATION OF TALL FESCUE GERMPLASM

de Araujo

ABSTRACT

M.Sc. MARCELO RENATO ALVES DE ARAUJO Plant Science (Agronomy)

AGRONOMIC EVALUATION OF TALL FESCUE (FESTUCA ARUNDINACEA SCHREB.) GERMPLASM

Eighty accessions of tall fescue (*Festuca arundinacea* Schreb.) were studied with the objective of assessing total genetic variability and to identify promising introductions. The variance components methodology developed by Comstock and Robinson (1952) was used to estimate the genetic and environmental parameters.

The results indicated that highly significant differences existed between accessions for all characters except first cut recovery. Broad sense heritabilities were high in magnitude for most of the characters except first cut dry matter yield and first cut recovery. This indicates that most of the characters were under strong genetic control. However, these high estimates of heritability are somewhat inflated, due to the existence of genotype-environment interaction.

Expected genetic advances from selection were calculated; however, their values are strictly applicable only if vegetative propagation of the selected material is assumed.

Genotypic and phenotypic correlation were obtained between the different characteristics measured. Genotypic correlations were slightly higher than phenotypic correlation for most of the characters. Some of the characters were found to be significantly associated with total dry matter yield. These correlation coefficients, however, were relatively low in magnitude.

Certain accessions appeared to have a good yielding capacity, being superior to the check cultivar, Alta, in this character. These accessions could prove useful as source material on which to base a breeding program.

SOMMAIRE

M.Sc. MARCELO RENATO ALVES DE ARAUJO Plant Science
(Agronomy)

L'EVALUATION AGRONOMIQUE DU MATERIEL GENETIQUE DE LA FETUQUE ELEVEE (FESTUCA ARUNDINACEA SCHREB.)

Quatre-vingts introductions de fétuque élevée (Festuca arundinacea Schreb.) sont étudiées afin d'évaluer leur variabilité génétique totale et afin d'identifier les plus prometteuses. La méthode des composantes de variance développée par Comstock et Robinson (1952) est utilisée dans l'estimation des paramètres génétiques et du milieu.

Les résultats indiquent qu'il existe une différence très significative entre les introductions pour tous les caractères sauf pour la reprise après la première coupe. L'héritabilité au sens large est grande sauf pour le rendement de la première coupe en matière sèche et pour la reprise après la première coupe. Ceci indique que ces caractères sont pour la plupart génétiquement contrôlés. Toutefois ces valeurs sont exagérées dû à l'interaction entre le génotype et l'environnement.

Les potentialités d'amélioration génétique par sélection sont calculées, toutefois celles-ci ne s'appliquent que si le matériel sélectionné est multiplié végétativement.

Les corrélations génotypiques et phénotypiques entre les différents caractères mesurés sont calculées. En général, les corrélations génotypiques sont un peu plus élevées que les corrélations phénotypiques. Il est établi que certains caractères sont significativement associés avec le rendement total en matière sèche. Cependant, ces coefficients de corrélation ne sont pas très élevés.

Certaines introductions semblent avoir une bonne capacité de rendement, en étant supérieures au cultivar témoin Alta. Ces introductions pourraient être utiles pour l'établissement d'un programme d'amélioration génétique.

DEDICATION

To my beloved wife Tania, my children
Marcello and Melissa, for their love,
encouragement, and unlimited patience,
this work is dedicated.

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CHAPTER I

INTRODUCTION

Tall fescue (Festuca arundinacea Schreb.) is a hexaploid ($2n = 42$) and cytogenetic evidence indicates that it is an allopolyploid (Peto, 1934; Crowder, 1953a). Tall fescue was first brought under cultivation in Europe, probably in England. It was introduced from the Old World to North America in the last century, but it took almost a half-century before the crop achieved any agricultural importance. Today in the United States, tall fescue is one of the most important forage crops. However, despite its good agronomic and quality characteristics, tall fescue is not extensively grown in Canada.

The production of new cultivars of the outcrossing grasses has in the past been based predominantly upon the direct exploitation of naturally occurring ecotypes to form the basis of new synthetic cultivars. However, with the increasing intensification of grassland use and, consequently, with the growing demands for sophisticated cultivars to satisfy specific requirements in terms of growth rhythms and quality of material, the breeder is faced with the need to consider more precisely the manner in which he may most efficiently produce these new cultivars.

Knowledge of the relative magnitude of the various genetic and environmental parameters for characters of economic importance is essential before more efficient breeding procedures can be employed. Since economically important plant characters are largely, if not entirely, quantitative in inheritance, they can be evaluated by the use of biometrical techniques. The use of biometrical evaluation permits the estimation of population genetic parameters such as means, genetic and environmental variances, heritabilities, genetic and phenotypic correlation coefficients, and the expected genetic advances from selection. Knowing the magnitude and the importance of such estimates enables the plant breeder to select parents, manipulate progeny, and isolate superior lines more efficiently. For example, the heritability concept is useful in determining to what extent differences among phenotypes are due to genotypic rather than environmental causes. Also, knowledge of the correlation between complex characters of low heritability, such as yield, and less complex characters which may have much higher heritabilities, would benefit plant breeders. It may be easier to select for a complex character by practising selection on a highly heritable character correlated with it.

The literature dealing with studies of the relative magnitudes of the various genetic and environmental parameters in tall fescue is not extensive. The variance component technique developed by Comstock and Robinson (1952b) seems to provide sufficient information about the genetic and environmental parameters among a number of progenies or different genetic lines. In this study, this method of genetic analysis was used.

The present investigation was designed to estimate (1) the total genetic variability, broad sense heritability, and expected genetic advances for dry matter yield and other agronomic characteristics in a population of 80 tall fescue accessions; and (2) the phenotypic and genotypic correlations among all characters under investigation. A further objective was to predict or select, on the basis of this genetic analysis, which introductions in our material are productive and have agronomically desirable characteristics. These selected introductions will be used as a source of germplasm for a breeding program.

CHAPTER II

REVIEW OF LITERATURE

2.1 Tall fescue as a forage crop

2.1.1 History and plant description

Tall fescue belongs to the genus *Festuca*, a genus of more than 100 species. It was introduced from Europe to North America in the nineteenth century.

Cowan (1956), in a review, gave a history of tall fescue. Botanically, tall fescue closely resembles meadow fescue, and therefore, Linnaeus, in 1753, classified both meadow and tall fescue as *Festuca elatior* L. In 1771 Schreber recognized a more robust type and called it *Festuca arundinacea*. However, Hackel, in 1882, gave the following classification which was followed by most scientists:

Festuca elatior L.
ssp. *typica* var. *genuina* Hack. (meadow fescue)
ssp. *arundinacea* (Schreb.) Hack. var. *genuina* Hack. (tall fescue)

It was Hitchcock (1935) who classified meadow fescue as Festuca elatior L. and tall fescue as Festuca elatior var. arundinacea (Schreb.). According to Cowan (1956), it was only in 1950 that tall fescue was called Festuca arundinacea (Schreb.).

The difficulties encountered by taxonomists in separating these two species have retarded, to some degree, the recognition of tall fescue as a crop of some value. However, Crowder (1953b) reported that tall fescue has a number of small hairs which are visible to the naked eye, whereas this characteristic is not found in meadow fescue. They can also be distinguished by chromosome counts, meadow fescue having $2n = 14$ chromosomes and tall fescue, $2n = 42$ chromosomes.

Tall fescue is a deeply rooted and strongly tufted perennial. The roots are tough and coarse, contributing to the formation of a good sod. This dense, coarse root system, which tall fescue develops, argues strongly for its use as a crop in sod waterways, along roadsides, and in places where a tough sod is required. As well, a thick, dense sod is an advantage to resist the trampling of the animals in pasturing on wet land. The basal leaves are dark green, broad and flat, the sheath is smooth and the ligule is short. The branched, panicle-type heads are 10-30 cm long and the spikelets are 8-18 mm long, with 8-10 florets. Only five to seven seeds are produced per spikelet, and they are similar in size and shape to Lolium perenne seeds (Buckner and Cowan, 1973).

2.1.2 Distribution and adaptation

Tall fescue is adapted to a variety of soils and a wide range of climatic conditions.

Tall fescue is found throughout Europe, North Africa, North America, South America, New Zealand and Australia in different types of soils, pH, temperature, rainfall, and soil moisture (Hoover et al., 1948).

Tall fescue has its best growth under cool season on heavy soils with adequate moisture and organic matter (Cowen and Streckling, 1968). At Oregon, tall fescue grows well on alkaline soils with a pH of 9.5 in Klamath Falls, and on acid soils with a pH of 4.5 in Astoria (Cowen, 1956). In the Bolivian altiplano, tall fescue is cultivated in semi-dry conditions. This semi-dry condition is characterized by a pluviometric precipitation which oscillates from 300 to 500 mm, with rainfall only during the summer (Gandarillas et al., 1965). Tall fescue grows well in the transition zone which separates the southern and northern regions of the United States. In this transition zone, neither cool nor warm season grasses are very well adapted (Juska and Hanson, 1969). According to Gandarillas et al. (1965), in the Bolivian altiplano, tall fescue is resistant to temperature of -7.4°C without problems in its development. At Knoxville, Tennessee, tall fescue grows where the January weekly temperature is around 4.4°C, and in the southern United States it grows where summer temperatures are very high (Buckner and Cowan, 1973).

2.1.3 Genetics

Tall fescue is a polyploid. The hexaploid number of 42 chromosomes was first reported by Levitsky and Kuzimina (1927) and has been found by Peto (1934) and Crowder (1953a).

Crowder (1953a) studied the meiotic chromosome behavior of 247 plants of tall fescue and cytological study showed that tall fescue has a hexaploid number of 42 chromosomes. An extra small chromosome was also found only in three plants studied. The chromosome behavior during the meioses was normal in the majority of cells observed, except for a very low incidence of multivalent pairing. The high frequency of bivalents suggests that an alloploid origin exists, since selective pressures appear to be against multivalent pairing.

Jenkins (1933) reported several successful interspecific and intergeneric hybrids between Festuca arundinacea and other Festuca ssp. and the Lolium genus. There has been considerable interest in such wide crosses. It provides an opportunity to study the homology to ascertain the possible evolution of tall fescue. According to Peto (1934), Ganton in 1898 was the first researcher to make a cross between Festuca and Lolium, but little information concerning these results is available. Peto (1934) showed that, in the diploid hexaploid cross between ryegrass (Lolium perenne) and tall fescue, a high proportion of ryegrass chromosomes paired with the chromosomes of tall fescue. Crowder (1953c) suggested that the genome of ryegrass and two or more genomes of tall fescue are phylogenetically related.

Although heterosis in many crop species is well documented, there are few papers written on forage crops. The work of Echeverri (1964) showed that heterosis was seldom expressed in tall fescue. Matheson (1965) reported that little or no heterosis was expressed for important characters of tall fescue, including forage yield. Studies made by Moutray and Frakes (1973) showed, however, that single-cross progenies derived from crosses between clones of diverse morphology, origins and anthesis date were superior to their parents in all characteristics. They suggest that tall fescue breeders could best utilize heterosis by including in their program material which was highly diverse in one or more of these three characters.

2.1.4 Agronomic potential and quality

The use of tall fescue has increased rapidly since the simultaneous release of the cultivars Alta and Kentucky 31 in 1940. Seed production went from a thousand kilograms in 1940 to 31 million kilograms in 1970. Also, in 1940 only a few thousand hectares were grown, while an estimated 20 million hectares were grown in 1970 (USDA, 1957, 1971). Today tall fescue is widely used for forage, turf and conservation purposes in different areas of the United States.

Tall fescue is used extensively for pasture, and it is tolerant of continuous close grazing. Performance of cattle grazing tall fescue pasture during the summer is generally not as good as that of animals grazing bluegrass (<u>Poa pratensis</u> L.) or orchardgrass (<u>Dactylis</u>

glomerata L.) pastures. However, due to the ability of tall fescue to provide more grazing days in the early spring and in the fall than other tall growing cool-season species, the hectarage of tall fescue in some regions of the United States has increased greatly (Lopez et al., 1967; Balasko, 1977; Rayburn et al., 1979).

According to Templeton and Taylor (1966) tall fescue gives excellent hay yields when properly fertilized. For highest quality hay, the grass should be harvested when the first seed heads begin to appear and certainly prior to the anthesis.

One of the criticisms of tall fescue has been its lack of palatability. This difficulty has been overcome to a certain degree by various management practices. When the grass is to be used for pasture the use of legumes associated with tall fescue is advisable. The legumes will add greatly to the palatability and nutritive value of the pasture. The choice of legume is dependent on its adaptation and on the utilization of the forage. Dobson et al. (1976) reported that through the association of tall fescue with legumes, the forage yield of the mixture was greater than that of the grass alone.

With the expansion of the use of tall fescue as a forage crop, many questions about its quality as a pasture and hay crop have arisen. Bryan et al. (1970) have stated that the digestibility of tall fescue indicates that it should be a high quality forage. Nevertheless, the poor performance of animals consuming it, particularly during the summer months, indicates a quality problem in the species. Rough hair coat, diarrhea, rapid respiration rates, and high rectal temperatures are usually associated with poor average daily gain of animals during late summer (Jacobson et al., 1970; Mott et al., 1971).

Perloline and loline are the two most important of several alkaloids found in tall fescue. The variation in the concentration of the alkaloids depends on factors such as cultivars, types of fertilizers, plant growth stage and environment (Gentry et al., 1969; Tookey and Yates, 1972). Buckner and Cowan (1973) have indicated that higher perloline levels are found during the summer months than during other months. Also, fertility levels that normally result in better pasture may result in higher levels of perloline. Gentry et al. (1969) studied the effect of fertilization with NPK on perloline content and found that application of NPK increased the perloline level. Also, it was demonstrated that nitrogen had a much greater influence on perloline level than phosphorus or potassium. However, if perloline content is primarily responsible for the poor performance of animals grazing tall fescue, plant breeding methods may be used to solve the problem.

Bush et al. (1970, 1972) have shown that perloline inhibited in vitro cellulose digestion by microorganisms in rumen fluid and that the growth of certain rumen bacteria was inhibited at perloline levels found in tall fescue. Therefore, the inhibitory effect of perloline on rumen microflora may explain the poor performance of cattle grazing during the summer.

According to Buckner et al. (1973) perloline concentration appears to be highly heritable, and thus appropriate methods could be used to select for low alkaloid content. In the same paper they suggested that it was possible to obtain rapidly a ryegrass x tall fescue hybrid population either low or high in perloline content.

Cornelius et al. (1974) have confirmed that it is possible to develop ryegrass x tall fescue hybrids low in perloline, selecting parents with low perloline level. However, some crosses of low perloline ryegrass x low perloline tall fescue produced some segregates very high in perloline. This indicates the presence of recessive genes for high perloline in some low perloline parents.

The use of interspecific hybridization of Lolium and Festuca species has been used to transfer the forage quality of Lolium to tall fescue, while maintaining the excellent agronomic quality of tall fescue. Buckner et al. (1977) released the cultivar Kenhy tall fescue. Kenhy is a synthetic of progenies of eleven, 42-chromosome derivatives of annual ryegrass x tall fescue hybrids.

Kenhy, according to Buckner et al. (1977), has the following advantages over Kentucky 31: (1) it is 12% higher in dry matter yield; (2) it has a higher digestibility; (3) it is lower in crude fiber and lignin; and (4) it is equal in perloline content and crude protein.

2.2 Variance components and heritability

2.2.1 Methodology

Variability exhibited by a population is of utmost importance to the plant breeder. Plant breeders have used the variation shown by progenies to understand the breeding behavior of the species in study.

Evaluation of the mechanism of inheritance in quantitative genetics research depends on valid assessments of genotypic values. However, the genotypic value of an individual must be obtained from observations made on its phenotype. The two components of the phenotype are the genotype (G) and environment (E); or, symbolically, $P = G + E$ (Falconer, 1960). The phenotypic variance, V_p, may be expressed as $V_p = V_G + V_E$, where V_G is the total genetic variance and V_E is the variance due to environment. This relationship holds if environmental deviation and genotypic values are independent of each other. If correlation between genotypes and environment exists, then $V_p = V_G + V_E + 2\ Cov_{GE}$, where Cov_{GE} is the covariance between the genotype and environment (Kempthorne, 1957; Falconer, 1960; Moll and Stuber, 1974).

According to Wright (1921, 1935) the total genotypic variance, V_G, is composed of three parts: additive genetic variance, V_A, dominance variance, V_D, and epistatic variance, V_I. The additive portion of the genetic variance reflects the degree to which progenies are likely to resemble their parents.

Excellent reviews of estimates of genetic variance for important crop species are given by Gardner (1963), Matzinger (1963), Cockerhan (1963), and Moll and Stuber (1974).

The estimation of genetic variance requires some kind of statistical technique applied to data collected on various parents and their progenies. Estimation of additive and non-additive genetic variance requires the use of appropriate mating and environmental designs. Cockerham (1963) classifies mating designs depending upon the number of parents per progeny. The most common mating systems are Designs I, II, III of Comstock and Robinson and the diallel cross techniques (Gardner, 1963).

Dudley and Moll (1969) have pointed out that in choosing a mating design it is preferable to utilize one which will provide the desired information. For instance, a one-factor design is enough to determine the presence of genetic variability.

The estimation of genetic parameters obtained from data in an analysis of variance table on the basis of expectation of mean square must meet the following assumption stated by Comstock and Robinson (1952a): (a) normal diploid and solely Mendelian inheritance; (b) no environmental correlation among progenies; (c) the progenies are not inbred and can be considered random members of some non-inbred population; (d) linkage equilibrium; (e) no epistasis, i.e., the effect on variation in genotype of any single locus is not modified by genes at other loci.

The assumption of diploid inheritance includes regular amphidiploids and can be modified to include autopolyploids, so long as α, the coefficient of double reduction, equals zero, and meiosis is regular (Kempthorne, 1957). Gardner (1963) observed that from the standpoint of statistical genetics, the behavior of allopolyploids is similar to diploids.

Knowledge of heritability of agronomic characters is very important for efficient selection. Plant breeders have used the estimations of genetic variance and its additive components to calculate heritability. Heritability can be divided into two types: (a) broad sense heritability, which is the ratio of total genetic variance to phenotypic variance; and (b) narrow sense heritability, which is the ratio of additive genetic variance to phenotypic variance (Dudley and Moll, 1969).

One common technique to calculate heritability is the variance component method developed by Comstock and Robinson (1952b). This method can be applied to either genetically different cultivars or families from a given generation.

One of the earliest papers on the statistical approach to inheritance in grasses was that of Burton (1951) who worked with pearl millet (<u>Pennisetum typhoides</u> (Burm.) Stapf and C. E. Hubb. The genetic variance was estimated by the equation $V_G = V_{F_2} - V_{F_1}$, where V_G was the total genetic variance, V_{F_2} was the variation in the F_2 population, and V_{F_1} was the variation in the F_1 population. The V_{F_1} was considered to be the environmental variation. The heritability was then calculated according to the formula

$$H = \frac{V_{F_2} - V_{F_1}}{V_{F_2}}$$

Obviously, the heritability estimation using such an equation may give considerable upwards bias. Parameters so obtained should be considered as the maximum heritabilities.

According to Faris and Lawson (1974), the most widely used methods for the estimation of broad sense heritability in forage plants are those developed by Macdonald et al. (1952), Kalton et al. (1952), and Burton and DeVane (1953).

Macdonald et al. (1952) used the average plant-to-plant variance among S_1 progenies of bromegrass clones (Bromus inermis Leyss). The mean S_1 variance consists of both environmental variance and genetic variance due to segregation. It was assumed that two S_o propagules of a clone in each replication were genetically equal, therefore the sampling error provides an estimate of environmental variance. If the S_o sampling error variance is subtracted from S_1 variance, the remainder is to be considered as total genetic variance. They divided the total genetic variance by the S_1 variance to give an estimation of heritability.

Kalton et al. (1952), using a procedure similar to that by Macdonald et al. (1952), subtracted the average S_o (parental clones) variance from the average S_1 (selfed progenies) variance in orchardgrass to obtain an estimate of genetic variance. The heritability was estimated by following the equation

$$H = \frac{S_1^2 - S_o^2}{S_1^2}$$

where S_1^2 = variance for the selfed progenies, which was considered to be an estimation of genetic variance plus environmental variance

and S_o^2 = variance for the parental clones which was considered to be an estimation of environmental variance.

These procedures were followed by studies of other workers (Baltensperger and Kalton, 1958; Lebsock and Kalton, 1954; Carlson, 1966). In some cases, clones and their open-pollinated progenies were used, while in other cases, clones and their selfed progenies were employed.

Burton and DeVane (1953), working with tall fescue clones computed genetic variance from the mean square for clones and error in the regular analysis of variance by separating the variance components according to the following formula:

$V_E + NV_G$ = the expectation of the clone mean square
V_E = the expectation of the error mean square
V_G = the total genetic variance
N = the number of replications

This method has the following advantages over those of Burton (1951), Macdonald et al. (1952), and Kalton et al. (1952):

1. It does not depend upon the assumption that environmental variance is equal for the segregating and non-segregating populations;
2. It reduces the amount of genotype x environmental variance carried in the estimate of genetic variance.

The total genetic variance so calculated may still contain variance due to dominance deviations and epistasis in addition to the additive fraction. For sexually reproducing species this can, therefore, give considerable upwards bias to estimates of gain by selection.

Many workers have used this methodology to calculate heritability. Among them are Brooks (1962), Burton (1974), Cooper (1959), Frakes et al. (1961), Gordon (1979), Keller and Likens (1955), Kneebone (1958), Kneebone et al. (1961), Lorenzetti (1966), Newell and Eberhart (1961), Schaaf et al. (1962), Scossorili et al (1963), Simonsen (1976, 1977), and Pott and Holt (1967).

Bubar (1964) estimated broad sense heritability for 38 clones of timothy (Phleum pratense L.) by calculating a single heritability value for each clone. He calculated environmental variance for each clone from the variance within the plots located in the replicates for the clonally propagated material. For the same clone he calculated the phenotypic variance from its selfed progeny in the same way. He considered that the parental clone provides an estimate of environmental plus "error" variances, and the selfed progenies provide an independent estimate of genetic plus environmental plus "error" variance. Heritability was estimated for each clone by the formula:

$$H = \frac{V_{s_1} - V_{s_o}}{V_{s_1}}$$

where V_{s_o} = the parental clone variance which was considered to be an estimate of $\sigma_e^2 + \sigma_E^2$

and V_{s_1} = the selfed progeny variance which was considered to be an estimate of $\sigma_g^2 + \sigma_e^2 + \sigma_E^2$

Falconer (1960) stated that it is important to realize that heritability is a property not only of a character but also of the population and of the environment. Since the value of heritability depends on the magnitude of all the components of variance, a change in any of those factors will affect it. Furthermore, the heritability is heavily dependent on plot size, planting date, planting density, and number of replications. It must be understood that interpretations of heritability must be treated very carefully, and the comparison of estimates for a particular character obtained by a different worker is of doubtful utility (Robinson, 1963). However, Robinson pointed out that a meaningful estimate of heritability is of use in estimating expected progress from adopting the program from which it was calculated. It is also a very useful concept in determining the relative importance of genetic effects which may be passed on to offspring, even in cases where it would be difficult to extrapolate to other populations.

2.2.2 Genetic variation and heritability in grass species

Macdonald et al. (1952), in studying the interrelationships of bromegrass clones, found a broad sense heritability estimate of 68% for height, but estimates for yield and spread were negative in value. The results led to the conclusion that for height there is maybe a fairly large portion of the observed variability that can be selected. Results for spread and yield, on the other hand, showed that environmental variance made up the major portion of the total variability. Negative heritabilities have been reported by Bubar (1964) and he attributed this to genotypic sensivity to the environment. Faris and Lawson (1970) attributed negative heritability estimates to intraclonal variation and to genotype-environment interaction.

Burton and DeVane (1953), working with several clones of tall fescue, reported high broad sense heritability values for some agronomic characteristics. They found estimates of 80%, 83%, and 90% for green weight of plant in 1950, green weight of plant in 1951, and disease resistance, respectively.

Lebsock and Kalton (1954), using the Kalton et al. (1952) procedure, studied genetic variation among strains of bromegrass. They reported that heritability estimates for fall vigor, hay vigor, height, and spread were 46, 60, 71, and 67 per cent, respectively.

These estimates, of course, contain not only additive genetic variance, but also that due to dominance deviation, epistasis and genotype-environmental interaction. Despite this fact, these workers considered that parameters obtained indicate that selection for certain characteristics in well-replicated, space-planted nurseries has a reasonable chance for success.

Kneebone (1958), using the variance component method, studied heritabilities of replicated clones of sand bluestem (Andropogon hallii Hack.). He reported broadsense heritabilities of 96% for height, and 77% for diameter. In the same paper, but using data from space-planted open-pollinated progenies, he reported heritabilities of 94% for height and 60% for diameter. The heritability estimation for both clonal and progeny tests indicates that genetic potential is present for these two characters, with height being more heritable than diameter.

Baltensperger and Kalton (1958), working with different accessions of reed canarygrass (Phalaris arundinacea L.) in a space-planted nursery, obtained significant differences among accessions for hay vigor and bloom date, respectively. Approximately 74% of the total variability for hay vigor was due to environmental effects, which indicates that genetic advance might not be obtained by phenotypic selection in spaced plantings.

Cooper (1961) reported the estimation of heritability for some important production characters in cultivars of ryegrass using two different procedures of calculation (parent-progeny correlation and analysis for full-sib families). He found that there is agreement between these two methods, and both methods provided encouraging figures for most of the characters studied. He also calculated the actual gain by selection in the second cycle and it was determined that for most of the characters the heritability calculated from the original cultivar provided a good indication of the short term response to selection.

Schaaf et al. (1962), studying different strains of crested wheatgrass (Agropyron desertorum (Fisch ex Link) Schult.), found a very high value for culm height heritability. The heritability values for forage yield were, however, very low. Low heritability of forage yield in this species has been reported by Knowles (1950, 1959).

Carlson (1966), working with clones and topcross progenies in reed canarygrass, found the estimates of genotypic variation in the clonal material to be in the order of 85% for flowering date and 18% for spring vigor. In the topcross progeny he reported estimates of 42% for annual dry matter yield and 74% for flowering date. According to Assay et al. (1968) about 60% of total genetic variation for forage yield is non-additive in reed canarygrass.

Matheson (1965), studying single-cross and F_2 progenies of tall fescue, reported evidence that forage yield is governed mainly by additive gene action. According to his data, one should expect greater progress selecting for yield in late-maturing cultivars. Also, he pointed out that heritability estimates indicated that most traits could be studied more effectively after the second year of plant establishment, due to the fact that environmental influence appears to be less pronounced at that time. Contrasting results were reported by Thomas and Frakes (1967), who found that plant height could be effectively selected for in the first year.

Faris (1970), working with timothy clones, used the Burton and DeVane (1953) procedure to calculate heritabilities. He reported that estimated values on a plot basis exceeded 80% for several characters. However, he pointed out that these estimates have been inflated, due to the existence of high GE interaction plus intraclonal variation effects.

Frakes and Matheson (1973), utilizing F_2 progenies of tall fescue, found broad sense heritability values of 84.8% and 74.5% for dry matter yield per plant and narrow sense values of 63.0% and 59.0% for the same character in two different years. Using the parent-progeny regression technique, the narrow sense values estimated for the dry matter yield were 50.8% and 43.0% in two different years. It was observed that the average broad sense heritability of almost 80% is in close agreement with those of Burton and DeVane (1953 - 80% and 83% for two years), and the three-year average of 76% reported by Frakes (1955). Since, in the narrow sense estimates, only additive genetic variance is used to calculate heritability, it is safe to conclude that in this study additive gene-action is the major factor involved in dry matter yield variation in tall fescue.

Subhanij (1974), studying the heritability of agronomic characteristics of tall fescue using diallel techniques, reported medium to high heritability estimates for plant spread and anthesis date and low values for plant height. Heritability estimates were based on parent-progeny relationships. Based on the diallel analysis it was evident that additive gene action was primarily responsible for dry weight. These results are in agreement with those reported by Frakes and Matheson (1973). Both additive and non-additive gene action influenced plant spread and anthesis date, while additive gene action was of major importance in the expression of plant height.

Simonsen (1977), working with a population of meadow fescue, found that the genetic variability for ear emergence is predominantly additive, while the non-additive variance is at least as great as additive variance for forage yield.

It is interesting to note that this review is in close agreement with that done by Moll and Stuber (1974), where it was stated that "most of the data reported points to one general conclusion: genetic variability of important agronomic traits is predominantly additive genetic variance. Non additive genetic variance also exists in nearly all species for many important traits, but it is generally smaller than additive genetic variance."

2.3 Genetic coefficient of variation and genetic advance from selection

Estimates of heritability do not always reflect the magnitude of genetic variation in a population. It does not always follow, therefore, that great advance can be made by selecting for characters having a high heritability value. The magnitude of the genetic variance must be considered. A genetic coefficient of variation (GCV) calculated by the formula

$$\frac{\sqrt{\text{genetic variance}}}{\bar{X}} \times 100$$

together with heritability estimate, would seem to give the best picture of the amount of advance to be expected (Burton, 1952).

Johnson et al. (1955) have emphasized that the GCV has considerable utility in facilitating the comparison of genetic variability in various populations and characters and in some cases may be useful in estimating genetic advance. However, Hanson (1963) has observed that converting to the percentage of the mean to remove units of measure yields a statistic of questionable meaning.

Whenever the plant breeder estimates genetic parameters for any quantitative trait in a population, he often estimates the expected genetic advance under selection for certain characters. Genetic advance is defined by Allard (1960) as the product of the intensity of selection, the estimate of phenotypic standard deviation, and the heritability estimate. According to Falconer (1960), intensity of selection depends only on the proportion of the population included in the selected group, provided that distribution of phenotypic values is normal.. Selection intensity can be calculated by dividing the height of the normal curve at the point of truncation by the proportion selected from the population. Genetic advance is often calculated by researchers working with heritability estimates of quantitative traits.

GCV ranging from 34% to 38% for forage yield has been reported for tall fescue by Burton and DeVane (1953). Also, they found that a genetic advance of 62.3% to 72.0% over the population mean would be expected for forage yield if selection was made on the top 5% of the population. They pointed out that due to the fact that the genetic variance may contain variance due to dominance and epistatic effects, the genetic advance values will only be strictly applicable if vegetative propagation of the selected material is assumed.

A reasonably high GCV of 29.5% for plant spread has been reported in Kentucky bluegrass by Berry et al. (1969). Lower estimates have been found in sand bluestem by Kneebone (1958), who reported a GCV for plant spread of 14.5%.

Schaaf et al. (1962), studying different strains of crested wheatgrass, found a very low GCV for plant height (GCV = 9.5%). Kneebone (1958), in bluestem, found a GCV of 17% for plant height.

2.4 Correlations

Knowledge of correlation between characteristics is useful in designing an effective breeding program for any crop. Complex plant characters, such as yield, are quantitatively inherited and influenced by genetic effects as well as effects due to the interaction of genotype with the environment. Yield by itself may not be the best criterion for selection to improve dry matter production. Hence, it is important to study the correlation between agronomic characteristics, which may have high heritability, and yield, which in most studies has low heritability (Falconer, 1960).

According to Falconer (1960) there are three major reasons to determine the relationship between two characters: (1) to determine the change brought about in a given character when selection is practised on another trait; (2) to study the genetic cause of correlation through the pleiotropic action of genes; (3) to examine the relationship between characters in a natural population.

The correlated variation of the two characters which can be directly observed is the correlation of phenotypic values, or the phenotypic correlation. The phenotypic correlation is a linear combination of genetic and envirohmental correlation. The genetic correlation is the correlation of breeding values while the environmental correlation is the correlation of environmental deviation, together with the non additive genetic deviation. If genetic correlations are high, attempts to obtain a response in one character by selecting for an associated trait may be worthwhile.

The extent to which various characters are correlated has been studied by a number of investigators. Macdonald et al. (1952), studying the relationship among S_1 progenies, open-pollinated progenies and clones of bromegrass, found high phenotypic correlation between yield and all characters investigated, except for height. For vigor and spread, they ranged from r = 0.68 to 0.92. Correlations between yield and height were 0.31, 0.74 and 0.44 for clones, self-pollinated progenies and open-pollinated progenies, respectively. Yield was also closely related to spreading ability (average, r = 0.79). This observation agrees with results obtained by Guenther (1949) and Knowles (1950), who found correlations of 0.76 and 0.63, respectively, between yield and spread, while working with bromegrass. Also, Macdonald _et al_. (1952) found a close association between fall vigor and spring vigor (average, r = 0.89), which suggests that the breeder may take vigor notes in the fall of the year of establishment. During this season the forage breeder usually has more time for taking notes than during the planting season.

Lebsock and Kalton (1954) calculated the degree of association between certain agronomic characteristics in different strains of bromegrass in a space-planted nursery. They used two different methods to obtain the degree of association of hay vigor with various other traits. The first method was that of computing simple correlation coefficients using mean values for each entry. Resulting correlations with hay vigor were as follows: 0.94, 0.76, 0.94, and 0.77 for fall vigor, height, spread and recovery, respectively. All coefficients were significant at the 1% level. In the second method they calculated the genotypic and phenotypic correlation. The phenotypic correlations between hay vigor and either height or spread were 0.41 and 0.79, respectively, while the genotypic correlations between the hay vigor and either height or spread were 0.38 and 0.81, respectively.

They concluded that spread is the most important component and that selection for this character could improve yield.

In a review paper, Nielsen and Smith (1961) summarized data indicating some of the associations of different bromegrass characters. According to that review there is a strong relationship between hay vigor and either height, fall vigor or spread. Also, forage yield is significantly correlated with spread, fall vigor and height.

Measurements of height, maturity, disease incidence, and forage yield were computed by Echeverri (1964) in an F_1 progeny of tall fescue. He found that height was correlated with the stage of maturity, but that forage yield was independent of the other characters measured.

Phenotypic and genotypic correlations among several characters of 15 different strains of Kentucky bluegrass were calculated by Berry et al. (1969). A significant phenotypic correlation was found between rust resistance and spread ($r = 0.63$). The genotypic correlation was also considered quite high, with an r value of 0.65. No significant correlation was found between growth habit and rust resistance or growth habit and spread.

Faris (1970), working with several timothy clones, reported estimations of phenotypic and genotypic correlation of several agronomic characteristics. He found very high estimates of genotypic and phenotypic correlation between spring vigor and total dry matter yield, clone diameter and clone volume, and clone diameter and total dry matter yield. He pointed out that since genotypic correlation between spring vigor score and total dry matter yield were positive and high in magnitude (average, r = 0.89), selection for either character could result in good progress in the other character. Clone volume was significantly correlated with clone diameter, but it was non significantly correlated with clone height. Therefore, it was concluded that a significant relationship between clone volume and total dry matter yield was mainly due to the significant correlation between clone diameter and total dry matter yield. Significant negative correlation between clone volume and total dry matter yield was observed.

Moutray and Frakes (1973) studied the relationship of certain agronomic characters in three different populations of tall fescue. The correlations between plant height and fall vigor ranged from 0.94 to 0.96; between plant height and anthesis date from 0.91 to 0.97; and between fall vigor and anthesis date from 0.81 to 0.92. The authors concluded that selection for either character could bring great advance in the other trait.

In reed canarygrass, Baker (1976) reported that height and basal diameter were significantly related with yield, but no correlation between yield and heading date was found.

Simonsen (1977), working with a clonal population of meadow fescue, reported that no correlation exists between the date of ear emergence and forage yield. Similar conclusions were reported by

Andonov (1970). However, Simonsen (1976) reported that in ryegrass there was a significant positive association between date of ear emergence and forage yield in first year of harvest, while no, or a slightly negative, association existed in the second year.

CHAPTER III

MATERIALS AND METHODS

3.1 Genetic material, experimental procedures and data collection

The genetic material studied in this experiment consisted of 80 introductions of tall fescue (*Festuca arundinacea* Schreb.) from throughout the world. The main reason for choosing these particular introductions was that they demonstrated a good capacity to survive the winter following the establishment year, as indicated by the Forage Inventory Publication of the Western Regional Plant Introduction Station of Pullman, Washington, USA. Alta, a cultivar of tall fescue, was included in the experiment as a check (Table 1).

The seed of each accession was germinated on moist paper towels. The seedlings were transplanted to plastic tubes containing a soil mixture of washed sand, loam and peat moss (1:1:1). A single seedling was transplanted into each plastic tube and flats of plants were grown in the greenhouse. Established seedlings were moved to a cold frame, outside the greenhouse, two weeks before they were planted in the field

TABLE 1. Introductions of Festuca arundinacea Schreb. used in the experiments, identified by the Macdonald accession number, the external accession number, and by the country of origin

	Macdonald accession number	External accession number*	Country of origin
1	MCF1	283297	Sweden
2	MCF2	283298	Yugoslavia
3	MCF3	283314	USSR
4	MCF5	260245	Germany
5	MCF6	283285	Poland
6	MCF8	269376	Afghanistan
7	MCF9	283291	Portugal
8	MCF10	283286	France
9	MCF14	208681	Algeria
10	MCF15	204446	Turkey
11	MCF17	194249	Greece
12	MCF18	PGR1861	USSR
13	MCF19	314686	USSR
14	MCF21	260246	Germany
15	MCF22	150156	Australia
16	MCF23	265367	Netherlands
17	MCF24	269894	Pakistan
18	MCF25	283285	Poland
19	MCF26	PGR1861	USSR
20	MCF27	289004	Hungary
21	MCF28	PGR1861	USSR
22	MCF29	PGR1863	USSR
23	MCF30	237516	Tunisia
24	MCF31	249738	Greece
25	MCF32	251122	Yugoslavia
26	MCF33	265357	Netherlands
27	MCF34	255416	Yugoslavia
28	MCF36	315430	USSR
29	MCF39	265359	Netherlands
30	MCF40	237559	Italy
31	MCF41	283295	U.K.
32	MCF42	283296	Sweden
33	MCF43	293293	France
34	MCF44	283292	U.K.
35	MCF45	283300	Poland
36	MCF46	283291	Portugal
37	MCF47	355324	USSR
38	MCF48	PGR2153	USSR
39	MCF49	PGR2154	USSR
40	MCF50	PGR2155	USSR

(table continued)

TABLE 1. (continued)

	Macdonald accession number	External accession number*	Country of origin
41	MCF52	223369	Iran
42	MCF51	283285	Poland
43	MCF54	PGR1865	USSR
44	MCF55	297905	Australia
45	MCF56	PGR1864	USSR
46	MCF58	297906	Australia
47	MCF59	PGR2152	USSR
48	MCF60	PGR2151	USSR
49	MCF62	283280	Israel
50	MCF63	355322	USSR
51	MCF64	265363	Netherlands
52	MCF65	311044	Roumania
53	MCF66	237178	Netherlands
54	MCF67	234719	France
55	MCF68	172423	Turkey
56	MCF70	265359	Netherlands
57	MCF71	265354	Netherlands
58	MCF72	235470	Switzerland
59	MCF73	265361	Netherlands
60	MCF74	253311	Yugoslavia
61	MCF75	250963	Yugoslavia
62	MCF76	234883	Switzerland
63	MCF77	234717	France
64	MCF78	234890	Switzerland
65	MCF80	295669	USSR
66	MCF81	203728	Uruguay
67	MCF82	235018	Germany
68	MCF85	231552	Algeria
69	MCF86	234717	France
70	MCF87	211032	Afghanistan
71	MCF88	235244	Spain
72	MCF89	264766	Netherlands
73	MCF90	229755	Iran
74	MCF91	234748	Iran
75	MCF92	265352	Netherlands
76	MCF93	297901	Australia
77	MCF94	283277	Portugal
78	MCF95	283276	France
79	MCF96	274617	Poland
80	MCF97	314684	USSR

*Accessions identified by numbers were provided by the Regional Plant Introduction Office, Pullman, Wa, USA. Accessions identified by letters plus numbers were provided by the Plant Gene Resources Centre, Agriculture Canada, Ottawa, Canada.

on June 6, 1978. The experiment was conducted at the Emile A. Lods Agronomy Research Centre at Macdonald College. Macdonald College is located at the extreme west end of Montreal Island, the geographical location being 45°25'N and 73°56'W, at an altitude of approximately 330 m, with a continental climate. The soil type of the experimental area is characterized as Ste. Rosalie clay, with a pH of approximately 6.2. The soil was prepared at the beginning of May, and 560 kg per hectare of 5-20-20 (NPK) was added to the soil.

Seedlings were space-planted in a randomized complete block design with two replications. Each plot comprised a ten-meter row containing ten plants, one meter apart. Plots also were one meter apart. A plot of Alta tall fescue was planted in every fifth row as a check. A border row was grown at each side of the experiment with the same spacing as that of the plots.

For each of the 80 accessions and also for the check cultivar, 8 plants per plot were evaluated. The plants on the end of each plot were not included in the evaluation because of border effect.

The following agronomic characters were measured on individual plants as described below:

1. Dry matter production.--Two cuts were taken in 1979; the first during the period of June 6-13, and the second on September 5-6. Each plant was uniformly cut at a height of 7 cm and its green weight recorded to the nearest gram. In addition, a representative sample from each plot (8 plants) was collected and weighed. This sample was

oven-dried and the dry matter percentage was calculated on a plot basis. The individual plant green weight from each plot was then converted to a dry weight basis. In the first cut plants were harvested individually at the early bloom stage, while in the second cut the entire plot was harvested in bulk.

2. Fall vigor.--A composite score was taken on October 15, 1978. The score was based on height, spread and leafiness, ranging from 1 (maximum vegetative growth) to 9 (minimum vegetative growth).

3. Spring vigor.--This was scored on May 2, 1979, on the same basis as fall vigor.

4. Growth score.--This was rated on a scale from 1 (the most decumbent plants) to 5 (the most erect plants).

5. Height.--This was measured in centimeters from crown to tip of tallest panicle, one week before the first cut.

6. Heading date.--The number of days from April 30, 1979, until the full appearance of heads.

7. First cut recovery.--This was scored one month after the first cut, on the same basis as for fall vigor.

8. Second cut recovery.--This was scored one month after the second cut, on the same basis as for fall vigor.

9. Spread.--The diameter of the plant in centimeters at the crown level was measured after after the second cut.

10. Volume.--This was calculated from spread and height by the following equation:

$$\text{Volume} = \pi R^2 h$$

where π = 3.1416

R = radius

h = height

11. Leaf rust incidence.--This was scored on a scale from 1 (the most healthy plants) to 9 (the most diseased plants) on August 24, 1979.

3.2 Statistical analysis

3.2.1 Means and ranges

The means and ranges for the variables within and over all accessions were calculated according to the procedures outlined by Steel and Torrie (1960).

3.2.2 Analysis of variance and heritability

The analysis of variance for the randomized complete block design was done according to the method outlined by Cochran and Cox (1957). Two types of analysis were performed: (1) The plot mean for each character was used for the statistical analysis. The form of the ANOVA and associated mean square expectations for the accessions are presented in Table 2. (2) Data from each individual plant were used to perform the analysis. This second type of analysis was used in order to observe if the variation within the accessions was greater or smaller than that between the accessions. The form of the ANOVA for this second type of analysis is also presented in Table 2. The linear models assumed for each of the variables were as follows

(a) For the plot mean data

$$Y_{ij} = \mu + R_i + G_j + E_{ij}$$

(b) For data on individual plants

$$Y_{ijk} = \mu + R_i + G_j + E_{ij} + S_{ijk}$$

where

Y_{ij} = the effect due to j^{th} accession in the i^{th} replication

Y_{ijk} = the effect due to the k^{th} plant in the j^{th} accession in the i^{th} block

μ = the effect due to the overall mean

R_i = the effect due to the i^{th} replication; $i = 1,2,\ldots,r$

G_j = the effect due to the j^{th} accession; $j = 1,2,\ldots g$

E_{ij} = the effect due to error associated with the j^{th} accession in the i^{th} replication

S_{ijk} = the effect due to error associated with the k^{th} plant in the j^{th} accession in the i^{th} block

Accessions were considered random and differences between them were tested using the accession x block mean square.

TABLE 2. Form of the variance analysis and mean square expectation

Source of variation	d.f.	M.S.	Mean square expectation	
			$X_{ij.} = \mu + R_i + G_i + E_{ij}$	$X_{ijk} = \mu + R_i + G_j + E_{ij} + S_{ijk}$
Blocks	r − 1		$\sigma_e^2 + g\sigma_r^2$	$\sigma^2 + p\sigma_e^2 + gp\sigma_r^2$
Accessions	g − 1	MS_2	$\sigma_e^2 + r\sigma_g^2$	$\sigma^2 + p\sigma_e^2 + rp\sigma_g^2$
Accessions x blocks	(r − 1)(g − 1)	MS_1	σ_e^2	$\sigma^2 + p\sigma_e^2$
Within accessions	rg(p − 1)			σ^2

Mean squares given in Table 2 were equated to their corresponding expectation and the resulting equations were solved for different estimates. The phenotypic estimate on a single plant basis, $\hat{\sigma}^2_{sp}$, and that on a replicated plot basis, $\hat{\sigma}^2_{rp}$, were calculated as follows:

$$\hat{\sigma}^2_{sp} = \hat{\sigma}^2_g + \hat{\sigma}^2_e$$

$$\hat{\sigma}^2_{rp} = \hat{\sigma}^2_g + \hat{\sigma}^2_e/r$$

where $\hat{\sigma}^2_g$ and $\hat{\sigma}^2_e$ are estimates of genetic and environmental variances, respectively, and r is the number of replications.

Heritability estimates in a broad sense were estimated from the following formulas:

(1) $H = \hat{\sigma}^2_g/\hat{\sigma}^2_{sp}$

= heritability in a broad sense on a single plant basis

(2) $H = \hat{\sigma}^2_g/\hat{\sigma}^2_{rp}$

= heritability in a broad sense on a replicated plot basis.

3.2.3 Expected genetic advance and genetic coefficient of variation

Expected genetic advance from selection (G_s) and the relative expected genetic advance from selection (RG_s) were calculated using the formulas:

(1) $G_s = K \hat{\sigma}_p H$

(2) $RG_s = \frac{G_s}{\overline{X}} \times 100$

where

G_s is the expected genetic advance from selection. It measures the differences between the mean genotypic value of the q selected lines, that is $\overline{as}$, and the mean genotypic value of the n original lines, $\overline{a}$, thus $G_s = \overline{as} - \overline{a}$.

K is the selection differential; its value depends on the percentage of the population selected (e.g., for 20% K = 1.46 (Allard, 1960)).

$\hat{\sigma}_p$ is the phenotypic standard deviation of the character in the original lines.

H is the broad sense heritability estimate.

Since the genetic variance, $\hat{\sigma}^2_g$, may contain variance due to dominance and epistatic effects, G_s values will only be strictly applicable if one assumes vegetative propagation of the selected plants. Only when a large part of the total genetic variance is due to additive genetic causes can the performance of the selected individuals be expected to predict the mean performance of its progeny.

Due to the fact that characters differ widely in their mean values and the scales of measurement, the genetic coefficient of variation (GCV) was also measured for each character as follows:

$$GCV = \frac{\sqrt{\hat{\sigma}^2_g}}{\overline{X}} \times 100$$

where $\hat{\sigma}^2_g$ and $\overline{X}$ are the genetic variance component and the mean of the character, respectively.

3.2.4 Estimate of phenotypic and genotypic correlations

To estimate the phenotypic and the genotypic correlation, covariance estimates were obtained by the analysis of covariance which is similar to the analysis of variance. The form of the analysis of covariance and associated mean cross product expectations for the accessions are presented in Table 3.

TABLE 3. Form of the covariance analysis and cross products expectations

Source	d.f.	M.P.	Expected cross products
Blocks	r-1		$Cov_e + g\ Cov_r$
Accessions	g-1	MP_2	$Cov_e + r\ Cov_g$
Accessions x blocks	(g-1)(r-1)	MP_1	Cov_e

The mean product expectations of the covariance analysis are analogous to the mean square expectations of the analysis of variance. accessions' mean product for the traits X and Y obtained from analysis of covariance was considered to be an estimate of the phenotypic covariance of the two characters.

The phenotypic correlation (r_p) between the characters was then calculated as follows:

$$r_p = \frac{MP_2(X,Y)}{\sqrt{MS_2(X)\ MS_2(Y)}}$$

where

MP_2 is the accessions mean cross product for the characters X and Y

$MS_2(X)$ and $MS_2(Y)$ are the accessions mean square for the trait X and the trait Y, respectively.

Genotypic correlation coefficients for the characters X and Y, based on the genotype means, were calculated in a similar way using the formulas given by Miller et. al. (1958) and Anand and Torrie (1963) as follows:

$$r_g = \frac{\hat{Cov}_g(X,Y)}{\sqrt{\hat{\sigma}^2_g(X)\ \hat{\sigma}^2_g(Y)}}$$

where

$$\hat{Cov}_g(X,Y) = [MP_2(X,Y) - MP_1(X,Y)]/r$$

$$\hat{\sigma}^2_g(X) = [MS_2(X) - MS_1(X)]/r$$

$$\hat{\sigma}^2_g(Y) = [MS_2(Y) - MS_1(Y)]/r$$

Phenotypic correlation coefficients were tested for their significance. The degrees of freedom required for testing the existence of phenotypic correlations were determined by subtracting one from the degrees of freedom for the accessions in order to account for the covariable. So far, a suitable test for significance of genetic correlations is not available (Faris, 1970; Pandey and Gritton, 1975; Ahmed, 1978).

The phenotypic correlations were tested using tables outlined by Steel and Torrie (1960).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Variation

Estimates of variance components for eleven variables are presented in Table 4. The estimate, $\hat{\sigma}^2$, which can be considered an estimation of plant-to-plant variation, was in most cases smaller than genetic variance of the accessions, except for the following traits; first cut dry matter yield, spring vigor, growth habit and first cut recovery. This estimate, $\hat{\sigma}^2$, contains not only variation due to plant-to-plant genetic differences, but also includes variance due to environmental factors, sampling error, and various interactions. For these reasons the between plant variation was not considered in the estimation of other genetic parameters. It must be kept in mind, however, that plant-to-plant variation exists and it is also confounded with GE interaction effects.

The analysis of variance for each of the 13 measured variables is reported in Table 5. It can be seen from this table that differences

TABLE 4. Estimates of variance components* for eleven characters of tall fescue

Character	$\hat{\sigma}^2_r$	$\hat{\sigma}^2_g$	$\hat{\sigma}^2_e$	$\hat{\sigma}^2$
First cut dry matter yield	0.1579	0.4061	0.6021	0.9071
Fall vigor	0.0024	0.2399	0.0120	0.1576
Spring vigor	0.0037	0.1889	0.0355	0.2087
Growth habit	-0.00009[a]	0.0704	0.0103	0.1208
Height	0.0118	77.1440	12.5063	34.8244
Leaf rust incidence	-0.0056[a]	2.2779	0.4563	0.2184
Spread	0.3733	21.8164	1.3158	8.8753
Heading date	0.0048	12.2193	0.6273	1.5328
First cut recovery	0.0117	0.0321	0.1972	0.2595
Second cut recovery	0.000003	0.8908	0.0414	0.1826
Volume	0.000005	0.000259	0.000020	0.000134

*Estimates were obtained from the ANOVA mean squares expectation, according to the linear model $Y_{ijk} = \mu + R_i + G_j + E_{ij} + S_{ijk}$.

[a] Negative estimate for which the most reasonable value is zero.

TABLE 5. Analysis of variance for thirteen characters measured in tall fescue

Character	Mean squares			F value
	Replications (1 d.f.)	Accessions (79 d.f.)	Error (79 d.f.)	($\frac{\text{M.S. accessions}}{\text{M.S. error}}$)
First cut dry matter yield	13.3503	1.5728	0.7155	2.19**
Second cut dry matter yield	0.0459	2.7219	0.3911	6.95**
Total dry matter yield	14.9364	5.8361	1.0200	5.72**
Fall vigor	0.2255	0.5117	0.0317	16.14**
Spring vigor	0.3634	0.4392	0.0616	7.13**
Growth habit	0.0177	0.1662	0.0254	6.54**
Height	17.8056	171.1434	16.8594	10.15**
Leaf rust incidence	0.0299	5.0393	0.4836	10.42**
Spread	32.2875	46.0581	2.4252	18.99**
Heading date	1.2032	25.2564	0.8177	30.88**
First cut recovery	1.7306	0.2939	0.2297	1.28 NS
Second cut recovery	0.0660	1.8457	0.0642	28.74**
Volume	0.00042	0.000556	0.000037	15.03**

** Significant at the 1% level.

NS Non-significant.

among accessions were highly significant ($P = 0.01$) for all characters except first cut recovery.

Estimates of variance components for the thirteen variables are presented in Table 6.

A study of the data in Table 6 reveals that the 13 characters studied differed greatly in the actual magnitude of their estimated variance components. The variance due to block effects ($\hat{\sigma}_r^2$) was always smaller than the other two components ($\hat{\sigma}_g^2$ and $\hat{\sigma}_e^2$).

Genetic variance estimates for all characters were higher than the environmental variance except for two traits, first cut dry matter yield, and first cut recovery score. This indicates that genetic variance component comprises the major proportion of the phenotypic variance component for most characters involved in the present investigation.

It must be understood that genetic effects are due to additive (breeding values), dominance and epistatic effects. The breeding value of an individual for a given trait is the sum of the average effects of the genes it carries, the summation being made over the pair of alleles at each locus and over all loci (Falconer, 1960). Dominance deviation, or the intra-allelic interaction, is the interaction between alleles at the same locus. Epistatic deviation, or interaction deviation, is the interaction between alleles at different loci. In this experiment the estimation of genetic variation cannot be separated into additive, dominance and epistatic effects. Therefore,

TABLE 6. Estimates of variance components* for thirteen characters of tall fescue

Character	$\hat{\sigma}^2_r$	$\hat{\sigma}^2_g$	$\hat{\sigma}^2_e$
First cut dry matter yield	0.1579	0.4061	0.7155
Second cut dry matter yield	-0.0005[a]	1.1654	0.3911
Total dry matter yield	0.0218	2.4079	1.0201
Fall vigor	0.0024	0.2399	0.0317
Spring vigor	0.0037	0.1889	0.0616
Growth habit	-0.00009[a]	0.0704	0.0254
Height	0.0118	77.1440	16.8594
Leaf rust incidence	-0.0056[a]	2.2779	0.4836
Spread	0.3733	21.8164	2.4252
Heading date	0.0048	12.2194	0.8177
First cut recovery	0.0117	0.0321	0.2297
Second cut recovery	0.000003	0.8908	0.0642
Volume	0.000005	0.000259	0.000037

*Estimates were obtained from the ANOVA mean squares expectation, according to the linear model $Y_{ij} = \mu + R_i + G_j + E_{ij}$

[a] Negative estimate for which the most reasonable value is zero.

the estimates calculated must be treated as the maximum total genetic variation. However, it must be remembered that according to Stuber and Moll (1969) and Breese and Hayward (1972), the additive genetic variance has exceeded dominance variance in most important agronomic characters that have been studied.

The only two traits which showed a total genetic variability smaller than environmental variance were the first cut dry matter yield and the first cut recovery score. It is believed that this was due to the fact that in the first cut each plant was harvested individually, so that eight days were required to do the harvesting. Thus, some plants had a growth period of up to one week longer than others. This likely contributed to the increase of variance due to environmental factors.

In the literature pertaining to tall fescue it was found that additive gene action is the main factor responsible for variation in dry matter production (Matheson, 1965; Frakes and Matheson, 1973; Subhanij, 1974). According to this evidence and looking at the results in Table 6, where a large amount of genetic variability is present, it is expected that selection for yield could be quite effective. However, these results do not agree with those reported by other authors (Hanson and Carnahan, 1956; Kalton et al., 1952; Macdonald et al., 1952; Simonsen, 1976; 1977), who found either low genetic variability for yield and/or dominance gene action being more important than additive gene action.

Results for height also indicate that there is a reasonable amount of genetic variability. According to results reported in tall fescue by Subhanij (1974) and in timothy by Faris (1970), the character height is controlled mainly by additive gene action. However, Matheson (1964), working with tall fescue and Simonsen (1976), working with ryegrass, indicated that for height, the non additive variance seems to have almost the same importance as additive genetic variance. Consequently, the practical significance of our estimation for this character must be treated with some caution. The result obtained from this study indicated that height was probably comparatively the variable most affected by environmental factors. Nevertheless, the height results prsented in Table 6 are in close agreement with those obtained by Macdonald et al. (1954), Lebsock and Kalton (1954), Kneebone (1958) and Schaaf et al. (1962).

Research carried out by Moutray and Frakes (1973), Simonsen (1976, 1977) and Cooper (1959, 1961) indicated that heading date in grasses is mainly governed by additive gene action. Results in Table 6 for heading date clearly indicate a large amount of total genetic variation. Therefore, we can expect that selection for this character will produce a satisfactory response.

Faris (1970) and Subhanij (1974), working with timothy and tall fescue, respectively, demonstrated that plant spread is controlled by additive and non additive gene action. The results obtained from the present study indicate that the estimate of genetic variance for spread was comparable to estimates reported by Lebsock and Kalton (1954), Kneebone (1958), Berry et al. (1962) and Faris (1970). This is a very important character in grasses, due to the fact that the number of tillers per plant is determined by the size of the plant spread. In tall fescue it has been observed that the number of tillers per plant was the most important component of forage yield (Nelson et al., 1977; Sleper et al., 1977).

For tall fescue there is little information about genetic variability for plant growth habit, leaf rust incidence, and vigor scores (spring vigor, fall vigor, aftermath recovery, etc.).

4.2 Heritabilities

Estimates of broad sense heritability percentages for measured variables were calculated from the components of variance. Heritabilities on a single plant basis and on a replicated plot basis were obtained and are presented in Table 7.

These heritability estimates include not only genetic variation, but also GE interaction. Therefore, the expectation of heritability estimates obtained by this procedure should be treated as the maximum possible heritability. Heritability estimation on a plot basis exceeded 80% for all characters with the exception of those estimates obtained for first cut dry matter yield and first cut recovery score.

Situations often appear when a plant breeder selecting for a character such as forage yield chooses a number of plants from his

TABLE 7. Estimate of broad sense heritability percentages for thirteen variables measured in tall fescue

Character	Replicated plot	Single plant
First cut dry matter yield	53.1	36.2
Second cut dry matter yield	85.6	74.8
Total dry matter yield	82.5	70.2
Fall vigor	93.8	88.3
Spring vigor 1979	85.9	75.4
Growth habit	84.7	73.4
Height	90.1	82.1
Leaf rust incidence	90.4	82.4
Spread	94.7	89.9
First cut recovery	21.8	12.2
Second cut recovery	96.5	93.2
Heading date	96.7	93.7
Volume	93.2	87.5

population. For example, suppose that dry matter yield happens to be highly correlated with another character. The breeder can select plants with respect to this character rather than purely at random, therefore increasing the possibility of picking superior genotypes. A character with a high heritability, obviously, would be more useful in this respect.

The estimates of broad sense heritability for dry matter yield were generally similar in magnitude to those reported in tall fescue by Burton and DeVane (1953), Frakes (1955) and Frakes and Matheson (1973). Similar results were obtained in reed canarygrass by Assay et al. (1968) and in timothy by Faris (1970).

Berry et al. (1969), Faris (1970) and Subhanij (1974) reported estimates of heritability for plant spread which are in close agreement with our results. However, lower estimates have been found (Lebsock and Kalton, 1954; Kneebone, 1958). Macdonald et al. (1952) even reported a negative estimate of broad sense heritability for plant spread.

The data on fall vigor, 1978, spring vigor, 1979, first cut recovery and second cut recovery, were recorded with the objective of measuring the vigor of accessions at different times. All of the vigor scores had high broad sense heritabilities except the second cut recovery estimation, which was only 21.8%. It is interesting to note that the first cut dry matter yield also gave a rather lower broad sense heritability. One can speculate that these two low estimates were due to the fact that the first harvest required 7-8 days. This would almost certainly increase variation due to environmental factors for first cut dry matter yield and probably also for the regrowth. In the literature there are few reports which mention broad sense heritability for vigor scores. Lebsock and Kalton (1954) reported a broad sense heritability estimation of 45% for fall vigor. Carlson (1966) found a broad sense estimation of 18% and 70% for spring vigor and fall vigor, respectively. Faris (1970), working with timothy, reported an estimate of 94% for spring vigor.

Heading date had the highest heritability value of 96.7%. According to the literature, there seems to be little dominance or interaction involved in the determination of heading date. Therefore, one can expect that a high heritability estimation should bring a fast response to selection. This was demonstrated by Cooper (1961) and Carlson (1966). These results were in close agreement with Moutray and Frakes (1973) who reported a heritability of 95% in tall fescue for heading date. Similar results were also reported for ryegrass by Cooper (1959, 1961); reed canarygrass by Carlson (1966), ryegrass by Simonsen (1976); and meadow fescue by Simonsen (1977). Selection for heading date among accessions, in the present study, would likely be effective.

The heritability estimate for leaf rust incidence was comparable to that previously obtained by Burton and DeVane (1955). Similar results were reported in Kentucky bluegrass by Berry _et al_. (1969). The heritability value for leaf rust resistance in this study was 90.4%.

Broad sense heritability for growth habit in the present study was found to be 84.7% on a plot basis. This is comparable to the finding of Berry et al. (1969) who, working with Kentucky bluegrass, reported a heritability estimation of 94.8%, and Faris (1970), who found an estimate of 96.0% for timothy.

The broad sense heritability estimation for height was 90.1% on a plot basis. According to Subhanij (1974), height in tall fescue is mainly controlled by additive genetic variance. One can speculate that the high heritability estimation for plant height in the present study indicates that selection for this character would be very effective. These results are in agreement with those found in bromegrass (Lebsock and Kalton, 1954), sand bluestem (Kneebone, 1958), and timothy (Faris, 1970).

A prime objective of quantitative genetic inquiry is the magnitude of the genetic variance as the basis for predicting genetic improvement in the selection program. Due to the fact that genotype x environment interactions are the source and part of the random error variance estimates and often introduce an upward bias, GE interaction may significantly affect the reliability of the variance estimate. Discrepancies between realized and expected response to selection will undoubtedly occur if expectations of progress are calculated from biased estimates of genetic variance. In this thesis it is fully recognized that calculations of the genetic parameters have been biased upward by GE interaction. However, these estimates give an idea of total genetic variability and through their estimation and through comparison made in this dissertation, they will be useful for the continuation of the program.

4.3 Genetic advances

Estimates of genetic advances from selection (G_s), relative genetic advance from selection (RG_s) of the top 20% of the population, and the genetic coefficient of variation for different characters measured, are presented in Table 8. Two different bases were used for calculating G_s and RG_s, depending on which heritability estimate was used. These were based on (1) a single plant basis; and (2) heritability estimates on a replicated plot basis.

Plant height, plant spread and heading date showed the highest G_s values, while leaf rust incidence and second cut recovery had medium values. Finally, first cut dry matter yield, fall and spring vigor, growth habit, first cut recovery and volume, had the lowest values. These results do not necessarily imply that selection for plant height, plant diameter and heading date would be more efficient than for the other characters, as they differ widely in their mean value and scales of measurement. It is evident from Table 8 that characters such as dry matter yield, leaf rust incidence and volume, which have a relatively low G_s, have high RG_s. This is mainly due to the lower mean values for these characters and a higher heritability and/or phenotypic variance.

TABLE 8. Estimates of genetic advance from selection (G_s), relative advance from selection (RG_s) and genetic coefficient of variation (GCV) for thirteen characters measured in tall fescue

Character		G_s*		RG_s**		GCV***
		Single plant	Replicated plot	Single plant	Replicated plot	
First cut dry matter yield	t/ha	0.54	0.65	22.74	27.55	26.99
Second cut dry matter yield	t/ha	1.31	1.40	45.89	49.07	37.87
Total dry matter yield	t/ha	1.82	1.97	34.94	37.87	29.27
Fall vigor score		0.64	0.66	16.27	16.77	12.37
Spring vigor score		0.53	0.63	17.10	21.56	14.06
Growth habit		0.32	0.34	7.58	8.14	6.32
Height	cm	11.14	16.67	13.10	13.73	10.32
Leaf rust incidence		1.92	2.01	93.25	97.60	73.00
Spread	cm	6.20	6.36	24.64	25.28	18.55
Heading date	days	4.74	4.81	16.35	16.62	12.06
First cut recovery		0.08	0.12	2.31	3.23	5.39
Second cut recovery		1.28	1.30	25.66	26.10	18.97
Volume	cm^3	0.021	0.022	46.31	50.33	36.02

*G_s values are given in actual units

** & ***RG_s and GCV are given in percentages.

An examination of the genetic coefficient of variation suggests that there was a relatively wide variation among entries for each character, except for growth habit and first cut recovery. High estimates, 73.32, 37.87, 36.02, 29.27, and 26.99 per cent were obtained for the traits leaf rust incidence, second cut dry matter yield, volume, total dry matter yield, and first cut dry matter yield, respectively. It is interesting to observe that height, spread and heading date, which had the highest G_s values had a relatively low GCV. On the basis of a relatively high heritability, RG_s, and GCV, one might conclude that rapid progress should be expected from selection for dry matter yield, volume and leaf rust incidence. Moderate progress should be expected from selection for height, diameter, heading date, first cut dry matter yield, fall vigor, spring vigor and second cut recovery. Less advance should be expected for growth habit and first cut recovery. These conclusions would, obviously, not hold for characters that are highly affected by the presence of non allelic interaction.

Expected selection responses are dependent on the magnitude of phenotypic variance in the population, on the heritability estimation and the proportion of plants selected. Therefore, the bias introduced in estimating heritability will be included in the calculations of the G_s values. Expected genetic advances from selection were generally in close agreement with the size of the heritability estimates for the different traits measured by the analysis.

A study of the forage yield data in Table 8 suggests that the forage yield of this grass could be increased up to 49.07% over the mean of all introductions, which is a substantial advance. If practical methods could be found for vegetative propagation of such plants, this advance could be realized by selecting superior individuals within the entries studied. Since tall fescue is a bunch grass, however, large scale vegetative propagation has been considered impractical.

4.4 Correlations

Knowledge of associations between plant characters is of considerable value in a breeding program. Linear association between two traits may be due to linkage or pleiotropic effect (Mode and Robinson, 1959). The phenotypic correlation is a linear combination of genetic and environmental conditions. Therefore, the proportion to which genotypic correlation makes up phenotypic correlation is of considerable value to the plant breeder, and is variable depending on the magnitude of the heritabilities of both traits.

Phenotypic and genotypic correlations between all possible characters are given in Table 9. Since Cov_g includes also the covariance of interaction effects between accessions and years (Cov_{gy}), estimates of Cov_g are biased as estimates of genetic covariation if covariance in accessions-year interaction effect exists. Such bias may be either positive or negative depending on whether Cov_{gy} is

TABLE 9. Phenotypic, rp (upper), genotypic, rg (lower), correlation coefficients among eleven characters in the tall fescue accessions

Character	Fall vigor	Spring vigor	Growth habit	Height	Leaf rust inci- dence	Spread	Heading date	First cut re- covery	Second cut re- covery	Volume
Total dry matter yield	0.14 0.11	0.35** 0.15	-0.13 -0.16	0.32** 0.37	-0.67** -0.78	0.53** 0.61	-0.04 -0.04	0.48** 0.76	0.61** 0.67	0.57** 0.65
Fall vigor		0.88** 0.65	-0.47** -0.51	0.21 0.26	-0.12 -0.13	0.21 0.16	0.14 0.15	0.50** +	0.18 0.19	0.15 0.16
Spring vigor			-0.46** -0.51	0.22* 0.26	-0.22* -0.25	0.23* 0.25	0.19 0.21	0.49** +	0.25* 0.26	0.23* 0.25
Growth habit				-0.10 -0.13	0.35** 0.41	0.06 0.07	-0.42** -0.46	-0.09 -0.22	-0.19 -0.21	-0.03 -0.04
Height					-0.16 -0.17	0.15 0.15	0.62** 0.46	0.33** 0.86	0.11 0.11	0.40** 0.40
Leaf rust incidence						-0.83** -0.73	0.23* 0.25	-0.64** -0.52	-0.80** -0.85	-0.63** -0.69
Spread							-0.17 -0.18	0.30** 0.62	0.80** 0.83	0.95** 0.96
Heading date								-0.01 -0.04	0.30** 0.31	-0.02 -0.02
First cut recovery									0.28** 0.54	0.34** 0.75
Second cut recovery										0.74** 0.77

\+ Genotypic correlation greater than 1.00.

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.
Significant values are 0.22 and 0.28 for the 0.05 and 0.01 levels of probability, respectively.

positive or negative. This situation is similar for the accession variance ($\hat{\sigma}^2_g$) except that this bias, if it exists, is positive since $\hat{\sigma}^2_{gy}$, being a variance, cannot be negative. Thus, the genotypic correlations were in reality estimates of

$$\frac{\mathrm{Cov}_g XY + \mathrm{Cov}_{gy} XY}{\sqrt{(\sigma^2_{gx} + \sigma^2_{gyx})(\sigma^2_{gY} + \sigma^2_{gy} X)}} \quad \text{rather than of}$$

$$\frac{\mathrm{Cov}_g XY}{\sqrt{(\sigma^2_g X)(\sigma^2_g Y)}}$$

Therefore, the biases referred to above could be a source of considerable bias in the estimation of genotypic correlations. However, examination of Table 9 reveals a rather general agreement, in both sign and magnitude. Generally, genotypic correlations were slightly higher than phenotypic correlations, while both were similar in sign, in all cases. This suggests that, for the most part, the character correlations are similar for genotypic and non-genotypic effects. Hence, the estimates of genotypic correlations were not seriously distorted by the fact that they reflect correlation in accessions x year interaction as well as in genotypic effects. Although some of the correlations were significant, the magnitude of the coefficients was below 0.5 for most of the associations.

4.4.1 Correlations with total dry matter yield

Total dry matter yield (TDM) was positively and significantly correlated with spring vigor, height, spread, first cut recovery, second cut recovery, and volume. It had a strong negative relationship with leaf rust incidence. Total dry matter yield was not associated with fall vigor, growth habit, and heading date. Examining the results, it appears that plant height, spreading ability of the plant and volume were the most important components of TDM. Nevertheless, because the correlation coefficient between TDM and height was low in magnitude ($rp = 0.32$), one could speculate that plant spreading ability is the most important trait as far as TDM is concerned. This fact seems to be supported by the association between volume and TDM. Volume is significantly correlated with both plant spread ($rp = 0.95$) and height ($rp = 0.39$); however, since correlations between volume and spread were very high, it is concluded that the most important factor associated with TDM is spread. Correlations between TDM and spread were highly significant, with the phenotypic correlation coefficient being greater than 0.5. However, the coefficient of determination ($rp^2 \times 100$) between TDM and spread is only 28%, which suggests that this correlation should be treated carefully. Other work, where it was found that forage yield was correlated with height and spread, has been reported for bromegrass (Lebsock and Kalton, 1954), tall fescue (Harris and Sedcole, 1974) and reed canarygrass (Baker, 1976). However, significant relationships between yield and spread, but not between yield and height have been reported in bromegrass (Macdonald et al., 1952) and in timothy (Faris, 1970).

Heading date was found not to be correlated with TDM. Similar results were also reported for tall fescue (Echeverri, 1964), timothy (Faris, 1970), reed canarygrass (Baker, 1976), ryegrass (Simonsen, 1976), and meadow fescue (Simonsen, 1977). Since there is no association between these two traits, it could be possible for the plant breeder to combine the extreme of maturity, either earliness or lateness, with high yielding ability in a single cultivar.

Highly significant association between TDM and spring vigor, first cut recovery and second cut recovery, was found. However, since the phenotypic correlation coefficients are lower in magnitude, except the correlation between TDM and second cut recovery (rp = 0.6), we should not put much emphasis on these traits. Moreover, the non association between TDM and fall vigor score seems to indicate that selection for superior plants during the establishment year is not possible.

4.4.2 Correlations with fall vigor

Positive and significant associations were found between fall and spring vigor, and first cut recovery. Negative correlation between fall vigor and growth habit was also observed. No significant relationships were observed between fall vigor and other variables.

4.4.3 Correlations with spring vigor

Positive and significant correlations were found between spring vigor and spread, first cut recovery, and second cut recovery. Spring vigor was negatively associated with plant growth habit and leaf rust incidence. No correlation was found between spring vigor and height, diseases, and heading date. Despite the significant correlation between spring vigor and spread and volume, the low magnitude of the coefficients appears to indicate that any selections on the basis of spring vigor are not useful as far as TDM components are concerned.

4.4.4 Correlations with growth habit

Growth habit score was positively correlated with disease incidence; however, it was negatively correlated with heading date.

Negative correlations between growth habit and height, volume, and TDM were not expected. The occurrence of negative correlations indicates that in a space-planted nursery a high growth habit score does not necessarily lead to highest dry matter yield. These results were similar to those reported by Faris (1970), who found growth habit to be negatively associated with height, volume and dry matter yield in timothy.

4.4.5 Correlations with plant height

Height was associated with heading date, first cut recovery and volume. Association between height and volume was highly significant, but it must be indicated that the rp value was only 0.40. Correlation between height and heading date (rp = 0.62) indicates that late maturing plants are the tallest in the population, as might be expected. Similar results were reported for tall fescue by Moutray and Frakes (1973).

No associations were found between height and leaf rust incidence, spread, and second cut recovery.

4.4.6 Correlations with leaf rust incidence

Disease incidence was highly significant and negatively correlated with spread, first cut recovery, second cut recovery and volume. Significant negative association between leaf rust incidence and volume is mainly due to the strong negative association between leaf rust incidence and spread (rp = -0.83). Leaf rust incidence was one of the factors which limits forage yield production (rp = -0.67). It is possible that by selecting disease-free plants, a substantial increase in TDM over the population mean can be reached.

4.4.7 Correlations between the remaining traits

Heading date was significantly correlated with second cut recovery, but no association was found between heading date and first cut recovery, and volume.

Both first and second cut recovery were correlated with volume.

It should be indicated that the correlations observed apply only to the specific accessions analyzed. The relationships may be quite different in other material in which different gene associations may exist.

4.5 Identification of promising material

One of the major goals of this study was to identify accessions which have good potential to use in a breeding program. Because tall fescue is not grown on a large acreage in Quebec, and also because it is necessary to assess the material with an appropriate point of reference, the use of a control cultivar was required. Alta tall fescue, a well known cultivar in the United States, was used as a check.

The means of the check cultivar, and the means and ranges of the accessions for various characters are presented in Table 10. In general, the control cultivar was agronomically better than the accessions. However, by examining the range of values for the accessions, it is clear that there is a large amount of variability between accessions. Results indicate that productivity may possibly be significantly improved by selecting introductions with agronomic values superior to the Alta cultivar. For example, the mean yield of Alta is 6.28 t/ha, while the best accession is about 48.7% higher.

In the year of 1979, twenty accessions produced total dry matter yields greater than the check cultivar. Table 11 presents these accessions with their agronomic characteristics.

TABLE 10. Means and ranges of accessions and means of Alta for different agronomic characteristics

Character	Accessions		Alta
	$\overline{X}$	Range	$\overline{X}$
First cut dry matter yield t/ha	2.36	1.06 - 4.71	2.67
Second cut dry matter yield t/ha	2.85	0.63 - 4.92	3.61
Total dry matter yield t/ha	5.21	1.83 - 9.34	6.28
Fall vigor in 1978	3.96	2.96 - 6.59	3.94
Spring vigor in 1979	3.08	2.03 - 5.22	2.89
Growth habit	4.19	2.96 - 5.00	4.16
Height cm	85.03	66.50 -115.25	88.17
Spread cm	25.16	12.25 - 35.06	29.46
Volume cm^3	0.045	0.009- 0.087	0.061
Leaf rust incidence	2.05	1.00 - 5.44	1.00
Heading date days	28.96	22.00 - 35.25	26.18
First cut recovery	3.62	2.78 - 5.06	3.31
Second cut recovery	4.97	3.25 - 7.15	4.51

TABLE 11. Agronomic characteristics of twenty introductions of tall fescue which outyielded the Alta cultivar in 1979

Accessions		Total dry matter yield t/ha	Relative total dry matter yield %	Fall vigor in 1978	Spring vigor in 1979	Height cm	Leaf rust incidence	Spread cm	Heading date days	First cut recovery	Second cut recovery	Volume cm^3	Growth habit
297905	Australia	9.34	148.7	4.00	3.09	90.31	1.00	24.87	25.37 E	3.28	4.75	0.04	4.15
289004	Hungary	8.41	133.9	3.12	2.18	95.12	"	26.31	35.25 L	3.43	4.06	0.05	4.03
297906	Australia	8.37	133.3	4.06	3.18	88.37	"	25.50	32.43 L	3.18	4.59	0.04	4.00
283280	Israel	7.86	125.2	2.97	2.03	79.75	"	28.56	23.75 E	3.16	4.40	0.05	4.53
314686	USSR	7.81	124.4	3.97	3.06	91.31	"	21.93	34.62 L	3.31	4.15	0.03	4.00
264766	Netherlands	7.69	122.5	3.90	2.90	84.37	1.25	28.25	25.50 E	2.78	4.28	0.05	4.18
265352	Netherlands	7.60	121.0	4.16	3.06	79.12	1.00	29.50	27.87 M	3.31	4.87	0.05	3.81
235470	Switzerland	7.46	118.8	4.06	3.09	89.50	"	35.06	31.56 L	2.97	3.62	0.08	4.00
265357	Netherlands	7.44	118.5	3.12	2.71	90.25	"	25.62	32.75 L	3.46	3.68	0.04	4.16
237559	Italy	7.29	116.1	4.03	3.37	83.75	"	25.93	27.56 M	3.53	4.56	0.04	4.75
234719	France	7.28	116.0	4.06	3.00	72.25	"	30.06	22.93 E	3.31	3.35	0.05	4.00
297901	Australia	7.15	113.8	4.03	3.12	89.00	"	26.00	32.43 L	3.12	4.34	0.04	4.06
249738	Greece	7.13	113.5	4.00	2.72	105.62	"	26.68	34.06 L	3.37	5.18	0.06	4.09
265361	Netherlands	7.09	112.8	4.16	3.12	86.62	"	29.62	31.25 L	3.31	4.12	0.06	4.31
355322	USSR	7.03	111.9	4.22	3.03	115.25	"	24.37	32.06 L	3.68	4.34	0.05	4.00
235018	Germany	7.00	111.5	4.09	2.90	96.12	"	26.81	32.18 L	3.97	5.15	0.05	4.50
283300	Poland	6.97	110.9	3.78	2.93	99.12	"	29.31	29.18 M	3.18	4.75	0.06	4.09
283276	France	6.68	106.0	4.00	3.12	83.68	"	23.31	24.50 E	3.46	4.09	0.03	4.31
274617	Poland	6.60	105.0	3.75	2.53	84.31	"	33.56	26.12 E	3.53	4.46	0.07	4.06
231552	Algeria	6.35	101.0	4.03	3.28	89.37	"	27.00	31.62 L	3.43	5.21	0.05	3.96
ALTA	USA	6.28	100.0	3.94	2.89	88.17	"	29.46	26.18	3.31	4.51	0.06	4.16

E = early maturing accession
M = medium maturing accession
L = late maturing accession

By examining Table 11 it seems that for these particular twenty introductions, neither spread nor volume appears to have an influence on total dry matter yield. One can observe that the entries which had the highest spread and volume (Introduction 235470 and Introduction 274617) did not have the highest yield. Also, Introduction 314686, which had the lowest spread and volume among the twenty accessions, produced 24.4% greater dry matter than the Alta cultivar. Therefore, it appears that something else is controlling dry matter yield in this experiment. It is suspected that either the number of tillers per plant or the number of tillers per unit of area could be controlling dry matter yield. Nelson et al. (1977) and Sleper et al. (1977) have found that, in tall fescue, the number of tillers per plant is the major factor responsible for dry matter yield.

Coefficients of correlation between TDM and spread and volume were statistically significant. However, coefficients of determination were only 28% for yield and spread, and 33% for yield and volume.

No correlation was found between heading date and TDM. By examining Table 11 one can see that plant maturity did not have any influence on yield. It is interesting to observe that the highest yield was obtained by an early maturing introduction.

Generally, the accessions had a better vigor during the spring of 1979 than during the fall of the establishment year. However, later in the season the vigor of the plant was decreased as it is evident by examining the results from first and second cut recovery.

Thus, on the basis of our somewhat limited results, these selected twenty accessions appear to represent a good source population on which to start a breeding program. The accessions represent diverse geographical areas. There is variation for dry matter yield, maturity, diameter, height and vigor. Finally, this material seems to be resistant to leaf rust. Therefore, appropriate breeding procedures, such as a polycross progeny test, which can make use of this diversity, could perhaps eventually lead to a development of a good cultivar adapted to Quebec conditions.

Because tall fescue is a perennial grass, results here presented are not absolutely conclusive. Information on persistence (longevity) of the accessions is necessary. Therefore, by the interpretation of one year's data, we cannot draw any definite conclusions about these introductions.

CHAPTER V

GENERAL DISCUSSION

5.1 Introduction

Improvement of crop characteristics depends primarily on the mode of action and interaction of the genes controlling variation and their distribution throughout the population. Consequently, any breeding program should be preceded by a complete analysis of the available variation.

Many of the methods used in a grass breeding program are those developed through corn breeding research. The majority of forage crops are cross pollinated with a high degree of self-sterility, and many grasses, although not all, are polyploids. The statistical genetic theory applicable to polyploids is much more complex than in the case of diploids and consequently, it has received relatively less attention.

In searching the literature it was evident that information about the relative magnitudes of various genetic and environmental parameters is not readily available for tall fescue. A number of papers have been published on the subject, and there has not always been complete agreement among authors.

A tall fescue breeding program was started at Macdonald College in 1978. This dissertation presents the initial information from the program. This study was designed to assess the magnitude of total genetic variation among different introductions. As well, the experiment assessed whether any of these accessions were superior to the standard cultivar Alta.

5.2 Biometrical survey of material

For the initial screening and survey of an unknown heterogeneous population, the genetic parameters of the characters under study need particular consideration. They will determine the possibility of recognizing superior genotypes by their phenotypes.

Decisions concerning the selection scheme to be used and the selection intensity to be imposed are influenced by the magnitude of genetic variances. Quantitative genetic studies of a wide range of crop species have indicated that the additive genetic component is usually more important than the non-additive component and, that in many cases, epistatic variance components can be ignored in the prediction of responses to selection. Therefore, it is reasonable to assume a predominance of additive genetic variance for most characters in a breeding population.

Heritability has value primarily as a method of quantifying whether progress from selection for a plant character will be relatively easy or difficult in a breeding program. In the present study, estimates of heritability were obtained by the variance component method. According to Burton and DeVane (1953) this procedure has the advantage of reducing appreciably the amount of GE interaction variance carried in the estimate of genetic variance. However, it is evident that heritability values reported in this study are overestimated due to the occurrence of a certain amount of GE interaction.

The utility of estimates of heritability is increased when they are used in conjunction with the selection differential, which is the amount that the mean of the selected accessions exceeds the mean of the entire group. The genetic advance is commonly predicted as the product of the heritability, the selection differential and the variation. Since characters differ in their mean values and scales of measurement, the Genetic Coefficient of Variation and the Relative Genetic Advance from selection were estimated.

Finally, the phenotypic and genotypic correlations between the different traits were determined. Genotypic correlation between traits provides a measure of the genetic association between characters and gives an indication of the characters that may be useful as indicators of more important traits. They also may help to identify characters that have little or no importance in selection programs.

5.3 Comments on the results

Total dry matter yield (TDM) in the 1979 growing season had a broad sense heritability of 83%, which is in agreement with results reported elsewhere for tall fescue by some authors (Burton and DeVane, 1953; Frakes, 1955; Frakes and Matheson, 1973). The GCV was 29.77%, the G_s value was 1.97 t/ha and the RG_s value was 37.87% over the accessions mean. According to these results there is a large amount of genetic variation for TDM. Based on the work done by Matheson (1965), Frakes and Matheson (1973), and Subhanij (1974), who reported forage yield in tall fescue to be controlled by additive gene action, one could speculate that the RG_s values found in this experiment are reasonable indications of expected progress.

Correlation coefficients between TDM and the other traits suggest that the important yield components are height, spread and volume. However, association between TDM and height is very low in magnitude with a coefficient of determination of only 10.2%. Coefficients of determination between TDM and spread, and TDM and volume, were 28% and 33%, respectively. These lower coefficients seem to indicate that there are other factors controlling TDM. It has been suggested that probably either number of tillers per plant or number of tillers per unit of area is a very important trait which should be looked at in the next growing season. Number of tillers per plant in tall fescue appears to be a very important yield component (Nelson et al., 1977; Sleper et al., 1977). According to Sleper et al. (1977)

the number of tillers per plant is controlled by both additive and non-additive gene action. Moreover, Yeh et al. (1976) reported that an increase of number of tillers in tall fescue is highly limited by the effects of competition. Therefore, it seems that when studying relationships between yield and components of yield, one should look at the number of tillers per unit of area rather than the number of tillers per plant.

Due to the fact that vigorous plants could have a higher yielding capacity, vigor scores were given to the accessions at different growth stages in 1978 and 1979. The heritabilities for different vigor scores were very high, except for the first cut recovery (H = 21.8%). By examining the RG_s values and the accession means, one can find that the fall vigor score mean could be decreased in one generation from 3.96 to 3.30; the spring vigor score mean from 3.08 to 2.42; the first recovery mean from 3.62 to 3.50; and the second cut recovery mean from 4.97 to 3.72. In this experiment a lower score indicates a more vigorous plant. Correlation coefficients of these traits with TDM were, however, low in magnitude. Only second cut recovery had a relatively satisfactory correlation coefficient (rp = 0.60).

For leaf rust incidence the high GCV and RG_s values seem to indicate that a straight phenotypic selection for healthy plants will be very effective. This character was highly negatively correlated with dry matter yield (rp = -0.67, rg = -0.79).

Heading date had the highest heritability value (H = 96.5%) and, according to some authors (Cooper, 1959, 1961; Moutray and Frakes, 1973; Simonsen, 1976, 1977), this character could be selected for by straight phenotypic selection. Moreover, since it is not correlated with TDM, it would be possible to select high yielding accessions in any of the maturity groups. This feature is demonstrated in Table 11, where the highest yielding introduction (297905) was in the early maturing group, and the second highest introduction (289004) was found in the late maturing group.

Finally, the results indicate that variables measured in this experiment are probably not the major components controlling yield. However, genotype environment interaction could have been very high during the 1979 season. Therefore, it may be possible that some traits had been greatly influenced by this source of error.

5.4 Relationship between spaced plants and sward conditions

The extrapolation of data on spaced plants to sward conditions is a matter of controversy among plant breeders.

Spaced plant nurseries have been used at Macdonald College throughout the years. Lawson (1961) studied five different lines of birdsfoot trefoil under three field conditions: (a) spaced plants; (b) drilled in row; and (c) broadcast. He was able to conclude that the relative performance of the different lines was the same for the three field plantings. Steppler and Bubar (1966) concluded that the suitability of spaced planting for evaluation depends upon the characters under consideration. Reliability decreases when the character interacts with the environment. Space-planted trials are useful in studying variability within a heterogeneous population, to compare lines for certain morphological and/or physiological traits, or to locate the best individual plants for a breeding program.

Recently, Lancashire and Harris (1978) pointed out that a space-planted nursery is very useful to compare genotypes for characters that can be evaluated visually, such as vigor, diseases and to eliminate poor or non-persistent lines.

Rumball and Armstrong (1974) reported that, although grown in a very artificial situation with little competition, cultivars that are distinctly superior as spaced plants are also better in sward conditions. Finally, most forage breeders agree that results from space-planted material must be interpreted carefully. However, for screening purposes, there is really no alternative to space planting.

CHAPTER VI

SUMMARY, CONCLUSIONS AND SUGGESTIONS

In this study several agronomic characters were investigated in eighty accessions of tall fescue. The accessions were space-planted in two replications in a randomized complete block design. The agronomic characteristics studied were dry matter yield, fall vigor in 1978, spring vigor in 1979, growth habit, plant height, plant spread, plant volume, heading date, first cut recovery, second cut recovery and leaf rust incidence.

Analyses of variance indicated that highly significant differences occurred among the accessions for all characters, except for first cut recovery. Generally, it seems that there is a considerable amount of total genetic variability for all of the characteristics measured. However, the portion of the genetic variability that may be attributed to additive genetic effects was not studied. Heritability estimates in the broad sense were generally high except for first cut recovery and first cut dry matter yield. Genotype-environmental variance may have inflated heritability in this study; therefore, it is suspected that these estimates are biased upwards.

Expected advances from selection were estimated and were found to be in close agreement with the magnitude of heritability estimates. Relative genetic advance from selection (RG_s) was high for dry matter yield, leaf rust incidence, and volume, indicating that selection for these characters could be effective. However, the genetic advance from selection (G_s) and the relative genetic advance (RG_s) can only be strictly applied if the selected plants are vegetatively propagated. Therefore, the estimation of G_s and RG_s should be viewed with caution. The genetic coefficient of variation (GCV) was also estimated. The high value of the GCV associated with a high heritability and a high RG_s is an indication that a straight phenotypic selection may be an efficient selection procedure. The highest GCV was obtained for leaf rust incidence, and the lowest was for first cut recovery.

Correlation coefficients among all characters under investigation were estimated. The genetic correlation coefficients were relatively higher than the corresponding phenotypic coefficients in most cases, but they were similar in sign, indicating that the significant phenotypic associations were mainly due to genetic causes. Total dry matter yield was found to have a positive significant association with spring vigor, height, spread, first cut recovery, second cut recovery and volume. However, because they were not high in magnitude these correlations should be interpreted with caution. Total dry matter yield was also negatively associated with leaf rust incidence. The characters studied seem not to be strongly associated with total dry matter yield. However, it would be useful to continue this study for another growing season. With the analyses of two years data the magnitude of these relationships may be modified, due to the fact that interaction between accessions and year would be removed. It appears that other factors may be more important in determining total dry matter yield in this experiment. We have speculated that either the number of tillers per plant or number of tillers per unit of area may be very important in dry matter production. Therefore, the measurement of these characters should probably be carried out in the next season.

Finally, it should be pointed out that the findings and conclusions reached in this study are somewhat limited, due to the fact that they represent only one year's data. Moreover, these results should be restricted to this set of eighty accessions.

Since heritability in this experiment is high, it is possible that straight phenotypic selection may be adequate to lead to an accumulation of favorable genes. This is supported by the literature survey of work on many perennial forage grasses, including tall fescue, which had indicated that additive gene action is the most important factor controlling many agronomic characters. Therefore, simple phenotypic selection will lead to a more rapid achievement per unit of time than progeny testing. However, if one feels that through phenotypic selection, advance in some characters, such as dry matter yield, will be difficult to obtain, the polycross technique would be a good method to use.

The following are recommendations for further investigation:

1. Carry out this research for at least one more year to obtain a measurement of the genotype-year interaction, and also to observe the persistence of the accessions.
2. Carry out progeny analysis to obtain precise estimates of the magnitude of additive genetic variance.
3. Include an evaluation of other important criteria in tall fescue breeding such as low alkaloid content, digestibility, and disease reaction.

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APPENDIX TABLES

APPENDIX TABLE 1. Means of forage dry matter yield

Macdonald College accession number	First cut dry matter yield t/ha	Second cut dry matter yield t/ha	Total dry matter yield t/ha	Relative* total dry matter yield %
MCF 55	4.70	4.63	9.34	148.7
27	3.49	4.92	8.41	133.9
58	3.72	4.65	8.37	133.3
62	3.38	4.48	7.86	125.2
19	3.91	3.90	7.81	124.4
89	4.67	3.02	7.69	122.5
92	3.89	3.71	7.60	121.0
72	4.35	3.11	7.46	118.8
33	3.46	3.98	7.44	118.5
40	2.79	4.50	7.29	116.1
67	4.05	3.23	7.28	115.9
93	3.81	3.34	7.15	113.9
31	3.08	4.05	7.13	113.5
73	3.64	3.44	7.08	112.7
63	3.21	3.81	7.03	111.9
82	3.17	3.83	7.00	111.5
45	3.04	3.91	6.97	110.9
95	2.62	4.06	6.69	106.5
96	2.81	3.79	6.60	105.1
85	1.92	4.43	6.35	101.1
ALTA	2.67	3.61	6.28	100.0
MCF 74	3.14	3.06	6.20	98.7
22	2.44	3.62	6.06	96.5
66	2.33	3.71	6.04	96.2
24	2.52	3.50	6.02	95.6
70	2.50	3.48	5.98	95.2
71	2.79	3.19	5.98	95.2
86	2.12	3.85	5.97	95.1
47	2.89	3.02	5.91	94.1
97	2.31	3.45	5.76	91.7
91	2.08	3.63	5.71	90.9
65	2.50	3.12	5.62	89.5
80	2.71	2.90	5.61	89.3
64	1.84	3.71	5.55	88.4
8	1.07	4.44	5.51	87.7
59	1.68	3.78	5.46	86.9
78	2.23	3.23	5.46	86.9
23	3.01	2.42	5.43	86.5
44	1.23	4.20	5.43	86.5
39	2.52	2.90	5.42	86.3
41	2.38	3.00	5.38	85.7

(table continued)

APPENDIX TABLE 1 (continued)

Macdonald College accession number	First cut dry matter yield t/ha	Second cut dry matter yield t/ha	Total dry matter yield t/ha	Relative* total dry matter yield %
MCF 81	1.54	3.74	5.28	84.1
6	2.22	3.01	5.23	83.3
36	2.97	2.21	5.18	82.3
43	1.28	3.88	5.16	82.2
77	1.47	3.56	5.03	80.1
10	1.83	3.16	4.99	79.5
2	1.70	3.22	4.92	78.3
42	1.96	2.92	4.88	77.7
28	1.84	3.01	4.85	77.2
75	2.17	2.64	4.81	76.6
76	1.85	2.92	4.78	76.1
29	1.84	2.92	4.76	75.8
68	2.22	2.52	4.74	75.5
87	1.79	2.64	4.43	70.5
94	1.55	2.75	4.30	68.5
90	2.50	1.77	4.27	67.9
9	1.59	2.56	4.15	66.1
30	2.04	2.02	4.06	64.6
5	1.33	2.70	4.03	64.2
17	1.73	2.24	3.97	63.2
1	1.34	2.62	3.96	63.1
46	1.18	2.77	3.95	62.9
14	1.69	2.09	3.78	60.2
3	1.71	1.95	3.66	58.3
52	1.60	2.01	3.61	57.5
50	2.96	0.65	3.61	57.5
51	2.49	1.02	3.51	55.9
54	2.57	0.68	3.25	51.7
32	2.42	0.73	3.15	50.1
21	1.64	1.38	3.02	48.1
18	1.92	0.91	2.83	45.1
56	1.83	0.99	2.82	44.9
15	1.75	0.93	2.68	42.7
60	2.01	0.63	2.64	42.0
34	1.13	1.35	2.48	39.5
26	1.74	0.72	2.46	39.2
25	1.66	0.69	2.35	37.4
48	1.48	0.73	2.21	35.2
88	1.06	0.83	1.89	30.1
49	1.06	0.76	1.82	28.9

*The control cultivar Alta, was considered to have a relative dry matter yield equal to 100%.

APPENDIX TABLE 2. Means of fall vigor in 1978

Macdonald College accession number	Fall vigor* in 1978	Macdonald College accession number	Fall vigor* in 1978
MCF 62	2.96	MCF 55	4.00
21	3.06	32	4.00
22	3.09	31	4.00
33	3.12	97	4.03
27	3.12	93	4.03
23	3.12	85	4.03
5	3.12	48	4.03
9	3.18	40	4.03
24	3.21	36	4.03
6	3.50	28	4.03
17	3.53	25	4.03
39	3.59	14	4.03
96	3.75	80	4.06
45	3.78	72	4.06
64	3.81	71	4.06
47	3.81	67	4.06
70	3.84	58	4.06
87	3.84	49	4.06
86	3.84	34	4.06
50	3.87	82	4.09
46	3.87	78	4.09
18	3.87	77	4.09
89	3.90	74	4.09
54	3.90	52	4.09
44	3.90	29	4.09
42	3.90	3	4.09
26	3.90	68	4.12
1	3.90	94	4.15
81	3.93	92	4.15
66	3.93	90	4.15
56	3.93	75	4.15
41	3.93	73	4.15
30	3.93	65	4.15
15	3.93	43	4.15
10	3.93	60	4.18
2	3.93	63	4.21
19	3.96	51	4.21
95	4.00	91	5.25
76	4.00	88	5.87
59	4.00	8	6.59

*Fall vigor score: 1 to 9,
where 1 = maximum vegetative growth and
9 = minimum vegetative growth.

APPENDIX TABLE 3. Means of spring vigor in 1979

Macdonald College accession number	Spring vigor* in 1979	Macdonald College accession number	Spring vigor* in 1979
MCF 62	2.03	MCF 3	3.09
27	2.18	97	3.12
5	2.21	95	3.12
24	2.34	93	3.12
23	2.34	87	3.12
21	2.37	73	3.12
22	2.40	44	3.12
96	2.53	71	3.18
9	2.59	70	3.18
64	2.65	58	3.18
29	2.68	49	3.18
81	2.71	46	3.18
33	2.71	66	3.21
31	2.71	34	3.21
86	2.75	78	3.25
42	2.78	75	3.25
18	2.78	59	3.25
2	2.84	51	3.25
1	2.84	52	3.25
28	2.87	36	3.25
25	2.87	85	3.28
89	2.90	56	3.28
82	2.90	48	3.28
50	2.90	80	3.31
6	2.90	32	3.31
45	2.93	68	3.34
41	2.96	94	3.37
39	2.96	40	3.37
67	3.00	14	3.37
76	3.03	60	3.40
63	3.03	47	3.40
17	3.03	90	3.43
92	3.06	74	3.43
43	3.06	54	3.50
30	3.06	15	3.50
19	3.06	26	3.53
10	3.06	65	3.65
77	3.09	88	4.34
72	3.09	91	4.62
55	3.09	8	5.21

*Spring vigor score: 1 to 9,
where 1 = maximum vegetative growth and
9 = minimum vegetative growth.

APPENDIX TABLE 4. Means of growth habit

Macdonald College accession number	Growth habit*	Macdonald College accession number	Growth habit*
MCF 87	5.00	MCF 55	4.15
9	4.84	70	4.15
40	4.75	74	4.15
41	4.75	49	4.12
34	4.71	65	4.12
2	4.62	30	4.09
77	4.62	31	4.09
21	4.59	45	4.09
10	4.56	47	4.09
24	4.56	51	4.09
28	4.53	60	4.09
62	4.53	17	4.06
29	4.50	23	4.06
82	4.50	50	4.06
18	4.46	75	4.06
81	4.46	93	4.06
86	4.43	96	4.06
59	4.37	97	4.06
94	4.37	27	4.03
5	4.34	52	4.03
15	4.31	76	4.03
73	4.31	78	4.03
95	4.31	1	4.00
26	4.28	19	4.00
44	4.28	58	4.00
48	4.28	63	4.00
3	4.25	64	4.00
39	4.25	67	4.00
46	4.25	72	4.00
80	4.25	71	3.96
43	4.21	85	3.96
56	4.21	88	3.96
25	4.18	6	3.93
89	4.18	90	3.93
22	4.15	66	3.90
32	4.15	68	3.90
33	4.15	91	3.90
36	4.15	92	3.81
42	4.15	14	3.68
54	4.15	8	2.96

*Growth habit score: 1 to 5,
where 1 = most decumbent plants and
5 = most erect plants.

APPENDIX TABLE 5. Means of height.

Macdonald College accession number	Height cm	Macdonald College accession number	Height cm
MCF 63	115.25	MCF 23	84.12
65	108.25	10	84.00
31	105.62	40	83.75
80	104.06	95	83.68
76	104.00	25	83.50
97	101.37	39	83.37
64	99.87	21	83.12
45	99.12	60	83.12
82	96.12	78	82.62
27	95.12	51	81.37
22	92.50	34	81.00
74	91.87	70	80.87
3	91.37	32	80.81
42	91.37	94	80.50
19	91.31	77	80.37
1	90.93	9	80.12
55	90.31	15	80.12
33	90.25	46	79.75
36	89.81	62	79.75
72	89.50	2	79.62
85	89.37	86	79.62
30	89.31	14	79.50
59	89.12	49	79.18
93	89.00	66	79.12
18	88.75	92	79.12
26	88.37	50	78.81
58	88.37	41	78.37
56	87.56	6	76.62
71	86.87	81	76.50
75	86.87	44	75.68
73	86.62	47	75.00
68	86.25	29	74.81
43	85.68	48	74.75
24	85.62	28	72.62
54	85.12	67	72.25
90	84.50	91	72.12
89	84.37	87	69.62
52	84.31	5	68.56
96	84.31	8	66.50
17	84.25	88	65.50

APPENDIX TABLE 6. Means of leaf rust incidence

Macdonald College accession number	Leaf rust incidence*	Macdonald College accession number	Leaf rust incidence*
MCF 96	1.00	MCF 28	1.00
95	1.00	27	1.00
94	1.00	24	1.00
93	1.00	23	1.00
92	1.00	22	1.00
91	1.00	19	1.00
88	1.00	17	1.00
87	1.00	15	1.00
86	1.00	10	1.00
85	1.00	9	1.00
82	1.00	3	1.00
81	1.00	2	1.00
80	1.00	1	1.00
78	1.00	89	1.25
77	1.00	29	2.03
74	1.00	97	2.93
73	1.00	5	3.00
72	1.00	14	3.28
71	1.00	52	3.81
70	1.00	76	3.84
68	1.00	90	3.96
67	1.00	48	3.96
66	1.00	36	4.06
65	1.00	75	4.15
64	1.00	47	4.18
63	1.00	54	4.46
62	1.00	32	4.46
58	1.00	60	4.50
55	1.00	18	4.50
46	1.00	59	4.53
45	1.00	21	4.53
44	1.00	51	4.59
43	1.00	26	4.65
42	1.00	25	4.68
41	1.00	56	4.78
40	1.00	50	4.87
39	1.00	49	4.93
33	1.00	8	5.00
31	1.00	6	5.18
30	1.00	34	5.43

*Leaf rust incidence score: 1 to 9,
where 1 = the most healthy plants, and
9 = the most diseased plants.

APPENDIX TABLE 7. Means of spread

Macdonald College accession number	Spread cm	Macdonald College accession number	Spread cm
MCF 72	35.06	MCF 78	26.00
71	35.00	93	26.00
66	34.68	40	25.93
96	33.56	33	25.62
70	32.87	56	25.31
81	31.06	87	25.31
64	31.00	9	25.25
41	30.62	58	25.25
67	30.06	36	25.06
45	29.93	2	24.87
73	29.62	28	24.87
68	29.56	55	24.87
92	29.50	63	24.37
46	29.31	30	24.25
44	29.25	14	24.18
74	29.25	95	23.31
91	29.00	10	23.25
43	28.93	88	22.81
62	28.56	97	22.43
86	28.37	19	21.93
89	28.25	21	21.93
77	28.06	15	21.37
24	28.00	47	21.37
29	27.62	60	20.75
42	27.56	59	20.12
52	27.25	3	20.06
85	27.00	1	19.87
75	26.93	51	19.62
82	26.81	34	19.25
31	26.68	32	18.93
65	26.62	18	18.87
90	26.50	25	18.50
76	26.37	48	18.37
27	26.31	50	17.93
94	26.31	5	17.62
23	26.25	6	17.25
80	26.25	49	16.87
17	26.18	26	16.37
22	26.06	8	13.06
39	26.00	54	12.50

APPENDIX TABLE 8. Means of heading date

Macdonald College accession number	Heading date (days)	Macdonald College accession number	Heading date (days)
MCF 27	35.25	MCF 10	29.50
19	34.62	39	29.50
31	34.06	66	29.25
15	33.25	45	29.18
14	33.00	70	29.12
32	32.87	6	29.00
52	32.68	91	28.62
56	32.50	21	28.31
36	32.43	23	28.12
58	32.43	17	28.06
64	32.43	92	27.87
93	32.43	43	27.75
33	32.37	40	27.56
60	32.25	5	27.18
18	32.18	81	26.81
76	32.18	47	26.37
82	32.18	28	26.18
54	32.12	49	26.18
59	32.12	96	26.12
63	32.06	24	25.62
65	32.06	89	25.50
34	32.00	97	25.43
22	31.93	55	25.37
30	31.87	80	25.37
90	31.68	48	24.93
85	31.62	29	24.68
72	31.56	95	24.50
71	31.37	94	24.31
88	31.37	87	24.12
25	31.31	2	23.81
51	31.31	62	23.75
8	31.25	44	23.68
73	31.25	86	23.43
26	31.18	41	23.12
74	31.18	50	23.12
75	31.06	77	23.06
68	30.93	87	22.93
1	30.75	9	22.75
3	30.56	46	22.68
42	29.62	78	22.50

APPENDIX TABLE 9. Means of first cut recovery

Macdonald College accession number	First cut recovery*	Macdonald College accession number	First cut recovery*
MCF 89	2.78	MCF 40	3.53
72	2.96	54	3.56
93	3.12	47	3.62
24	3.12	29	3.62
90	3.15	86	3.65
62	3.15	42	3.65
74	3.18	28	3.65
58	3.18	63	3.68
45	3.18	77	3.71
50	3.21	76	3.71
6	3.25	65	3.71
55	3.28	51	3.71
36	3.28	10	3.71
97	3.31	87	3.75
92	3.31	66	3.75
80	3.31	94	3.78
73	3.31	32	3.78
67	3.31	15	3.78
19	3.31	9	3.78
31	3.37	2	3.78
23	3.37	48	3.81
18	3.37	39	3.81
85	3.43	17	3.81
71	3.43	58	3.84
30	3.43	64	3.87
27	3.43	5	3.87
21	3.43	75	3.93
3	3.43	26	3.93
95	3.46	82	3.96
33	3.46	44	3.96
25	3.46	1	3.96
22	3.46	91	4.06
14	3.46	43	4.09
52	3.50	56	4.11
96	3.53	59	4.12
81	3.53	34	4.21
70	3.53	49	4.50
68	3.53	46	4.50
60	3.53	88	4.78
41	3.53	8	5.06

*First cut recovery score: 1 to 9,
where 1 = maximum vegetative growth and
9 = minimum vegetative growth.

APPENDIX TABLE 10. Means of second cut recovery

Macdonald College accession number	Second cut recovery*	Macdonald College accession number	Second cut recovery*
MCF 71	3.25	MCF 45	4.75
29	3.34	92	4.87
76	3.46	90	4.90
72	3.62	94	4.93
33	3.68	91	4.93
66	3.75	88	5.00
41	3.78	80	5.00
9	3.96	39	5.06
87	4.06	30	5.06
27	4.06	47	5.09
95	4.09	10	5.09
86	4.09	36	5.12
73	4.12	82	5.15
70	4.15	76	5.15
42	4.15	31	5.18
19	4.15	3	5.18
2	4.18	85	5.21
44	4.21	96	5.28
28	4.25	75	5.50
89	4.28	52	5.62
77	4.28	56	5.87
74	4.28	1	5.96
24	4.28	48	6.00
68	4.31	59	6.03
93	4.34	49	6.03
63	4.34	15	6.03
17	4.34	21	6.09
23	4.37	14	6.12
62	4.40	34	6.25
64	4.43	32	6.25
96	4.46	54	6.28
81	4.46	51	6.31
43	4.50	60	6.37
40	4.56	26	6.56
22	4.56	50	6.62
58	4.59	25	6.78
46	4.62	5	6.84
78	4.65	18	7.00
65	4.75	8	7.06
55	4.75	6	7.15

*Second cut recovery score: 1 to 9,
where 1 = maximum vegetative growth and
9 = minimum vegetative growth.

APPENDIX TABLE 11. Means of volume

Macdonald College accession number	Volume (cm^3)	Macdonald College accession number	Volume (cm^3)
MCF 72	0.08	MCF 17	0.04
71	0.08	36	0.04
96	0.07	56	0.04
64	0.07	40	0.04
66	0.07	39	0.04
45	0.06	78	0.04
70	0.06	58	0.04
74	0.06	94	0.04
65	0.06	55	0.04
73	0.06	80	0.04
31	0.06	97	0.04
81	0.05	9	0.04
68	0.05	2	0.03
41	0.05	95	0.03
76	0.05	14	0.03
80	0.05	10	0.03
43	0.05	87	0.03
63	0.05	28	0.03
42	0.05	19	0.03
82	0.05	21	0.03
92	0.05	3	0.02
46	0.05	15	0.02
24	0.05	1	0.02
89	0.05	59	0.02
27	0.05	60	0.02
67	0.05	47	0.02
44	0.05	88	0.02
62	0.05	18	0.02
85	0.05	51	0.02
75	0.05	34	0.02
52	0.05	32	0.02
77	0.05	25	0.02
86	0.05	50	0.02
22	0.04	48	0.02
93	0.04	26	0.01
90	0.04	6	0.01
91	0.04	49	0.01
33	0.04	5	0.01
23	0.04	54	0.01
29	0.04	8	0.01