THE GENETICAL EXAMINATION OF 'GRASSLANDS ARIKI' RYEGRASS

Lolium [(multiflorum x perenne) x perenne]

A thesis presented in partial fulfilment
of the requirements for the degree
of Master of Agricultural Science
in Plant Science.

John Richard Sedcole

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Preface.

'Grasslands Ariki' ryegrass - Lolium [(multiflorum x perenne) x perenne] - has been established in New Zealand as a successful pasture variety. While some genetic parameters were determined during its breeding programme, no diallel cross analyses have been performed on 'Ariki'. It was for this reason that this particular experiment was suggested to me.

The inclusion of two treatments arose from a cynical remark passed by W. Harris, regarding the failure on the part of plant breeders to use simulated swards. The experiment was designed to determine the levels of genotype-by-environment interaction in 'Ariki' ryegrass.

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CHAPTER I

Review and Discussion of the Relevant Literature.

Methods of assessing the sward performance of forage plant genotypes.

Fejer (1959) has suggested, without qualification, that the average distance between surviving plants in a ryegrass sward sown at 15 lb. of seed per acre is 1½ inches. In most forage-plant breeding programmes, however, plants are selected on the basis of their performance as widely spaced plants. Spacings vary, but typically are between 18 inches and 30 inches.

The extent to which spaced plant assessment gives an accurate indication of sward performance has been the subject of a number of reports which will be discussed below.

Fejer (1959) points out that intra-specific competition, although a possible source of density-by-genotype interaction both in vegetative and seed production, has been largely ignored by plant breeders. This has not always been so; Jenkins (1931) in an early paper on forage plant breeding, discusses Aberystwyth Plant Breeding Station methods of screening large numbers of plants for selection in a breeding programme. Initial selections were made from spaced plants (2 feet apart). Perhaps 100 of an original population of 5,000 would be selected. Three methods were then employed to examine these selections more critically.

Clone Method

Here the single plants were broken up into plantlets and each clone (that is, the plantlets from each single plant) spaced out separately for examination.

Tiller-bed method

Here the selected plants are broken up into tillers which are planted two inches apart in a "broadcast" manner. Jenkins (loc.cit.) points out that by this method the single plant can be studied under conditions approximating those of an ordinary sward. Stapledon (1931) also used this method in a cocksfoot breeding programme.

Tiller-row method

This method is similar to the above, except that the tillers are planted out in rows. As the original tillers soon lose their identity, the entire row forms the basis of their examination. Jenkins (loc.cit.) claims that tiller rows have shown up the individuality of the plant to a considerably higher degree than does the Clone method.

In both these latter two techniques the plant is being subjected to rather more competition than would be experienced by the singly-spaced plants.

Levy (1933) discussed the technique then being used by pasture plant breeders of Grasslands Division, D.S.I.R. for examining lines for breeding purposes. 1/1,000th acre plots, 6-2/3rds by 15 links, (4.4 by 9.9 feet), were sown where sufficient seed was available; otherwise rows, two feet apart, were used.

Notes, visually scored, were made of speed of establishment (sic), tillering and spread; relative growth, density of sward; recovery after cutting, persistency, date and extent of flowering; disease susceptibility and so on.

Within a year a very good idea of the performance of each line could be obtained.

Seeds of those lines which proved under plot trial to be worthy of further critical study were sown in boxes and the seedlings that established were planted out, two feet apart, in plots of ten plants in a row. Later, Dr. P.C. Barclay (pers. comm) altered this so that each plot of ten plants was two adjacent rows of five plants each.

Of the 4,000- 5,000 single plants thus arranged usually some 150 were selected on the basis of their performance in a two-or-thre-year trial. These plants, uplifted and broken into plantlets, were replanted as rows and/or single plants, and examined for a further one or two years. Subsequent genetical examination of the most promising lines of the 150 "super types" was not extensively practised at "Grasslands" at the time Levy was writing (1933). More recently progeny testing has been extensively used to select élite parents on the basis of their "breeding value", (e.g. see Barclay, 1960).

Since the time of Levy's paper (Levy 1933), the broadcast and rwo plots have become disregarded, and a considerable amount of work has been carried out on single-spaced plant assessment alone. Broadcast plots have been used only to assess the merit of the final product.

Any movement away from sward conditions in plant assessment should be accompanied by satisfying evidence that the non-sward assessment is an adequate measure of the relative performance of that plant, or genotype. Attempts to validate single-spaced plant assessments have been conflicting (Eyres 1960).

Stapledon & Davies (1930), Milton (1930) and Williams (1948, unpub.) were those cited by Lazenby (1957a) as having found sward performance to be adequately indicated by spaced plant performance. Lazenby suggested that failure of American work (some of which is discussed below) to show similar results was due to the inaccuracies resulting from the visual assessment of the spaced plants.

Stapledon & Davies' (1930) conclusions were based on the performance of a number of species, rather than strains within species. Furthermore, the spaced plantings were in a separate experiment from the broadcast plots. The relationship was held to be a "general trend" and was not defined very precisely.

Milton (1930) examined the relative performances of five lines of Aberystwyth-bred grasses, viz. a hay type perennial ryegrass, two strains of timothy and two strains of cocksfoot. They were sown in rows two feet apart, as well as in broadcast plots. Thus the extrapolation of Milton's conclusions to sward spaced plant comparisons is not really valid. Even so, his results in fact showed that the two timothy lines, and to a lesser extent the cocksfoot lines, did differ in their performance relative to each other in different plantings.

Lazenby's (1957a) conclusions from an examination of four strains of perennial ryegrass, viz. Devon Eaver, S24, Irish, and New Zealand, were that the performance rankings of the varieties were similar, whether they were sown as spaced plants (24 inches by 18 inches) or swards (20 lb. of seed per acre, with 1 lb. each of S100 white clover and S184 wild white clover).

His data, however, show not only significant variety-by-sowing method interactions for yield in the second year (although not in the first) but also that every broadcast/spaced plant comparison showed different rankings.

Murphy (1952), reviewing some of the available literature on the relationships between sowing methods, mentioned that McDonald <u>et al</u> (1952) were amongst those reporting a satisfactory relationship. McDonald <u>et al's</u> paper, however, shows that there was no significant correlation between family performance in rows and as spaced plants.

Wilsie (1949), Hawk & Wilsie (1952) and Murphy (1952) found positive correlations between the performance of lines in different methods of planting. The general criticism of this correlation approach is that a significant positive correlation may not mean that any <u>one</u> line or plant chosen at one level of competition will perform relatively as well at another level of competition.

This is borne out by Wilsie's (1949) data with bromegrass. While correlations were high for yields of strains sown in rows (presumably nine inches apart) and solid drilled plots, some lines deviated noticeably from the pattern established by the correlations. Of eight strains tested in rows and broadcast plots only the first three were ranked the same in either planting.

Murphy's own data (1952) show seven significant yield interactions between planting methods and varieties in 19 experiment analyses. His summary of the data does not give sufficient evidence to support his contention that "the breeder can use any of the ... methods of planting investigated for isolating selected plants which possess high yield potential". For example, the correlation Murphy obtained between yields of spaced-planted poly-cross progeny and broadcast sown poly-cross progeny was +0.473, a highly significant value. This was obtained using five clones of <u>Dactylis glomerata</u>, five of <u>Bromus inermis</u> and nine of <u>Festuca rubra</u>. His correlation of +0.473 is given with a range of -0.93 to +0.95. This large error in the correlation suggests that the yield of progeny as spaced plants is a quite unacceptable indicator of their relative yield in swards.

Ahlgren <u>et al</u> (1945) examined a large number of correlations between different characters and methods of evaluation of <u>Poa pratensis</u> strains. They concluded that there was little or no relation between estimated yields of the selections grown as spaced-planted nursery rows (2 feet by 3½ feet) and yields in swards.

Kramer (1947), using <u>Poa pratensis</u>, reached similar conclusions comparing widely spaced plants (two feet by two feet) with mowing from a simulated sward established with plants at seven-inch spacings. There was a consistent lack of relationship between the characteristics that denote or are associated with vigour of individual plants and yield of forage from mown plots.

Knowles' (1959) data on Agropyron cristatum also show that spaced plant performance is an inadequate predictor of sward performance. As Synthetic 2 generation material was used here, his argument loses a considerable amount of weight. This is because the Synthetic 2 generation is likely to contain a considerable amount of inbred, and therefore less vigorous material, most of which would be eliminated by the highly competitive conditions prevailing in the sward, but would probably survive as single plants. This could be a source of considerable interaction (R.C. Clements, pers. comm.).

Oldemeyer & Hanson (1955), from the data of the progeny of a diallel cross between five Dactylis glomerata plants, where progeny were sown as spaced plants and broadcast swards, concluded:

"It appears that broadcast seedlings are more desirable for testing than spaced plants."

This was in spite of a 0.55 correlation between spaced plant and sward performances for yield.

Similarly, Grisson & Kalton (1956) found correlations between the yield of progenies of Bromus inermis in swards and spaced plants (three feet by three feet), to vary between -0.28 and +0.45, depending largely on the climate. They concluded that spaced plant performance is of little value in predicting sward performance.

Proudfoot (1957) found a similar lack of agreement between yield rankings of Lolium perenne strains as swards and as single plants. This discrepancy tended to disappear when single plant production was related to the actual area occupied by the basal portions of the plant. He suggests that the use of the yield/basal-diameter ratio in strain evaluations will give a more accurate picture of the potential yield under sward conditions.

Beddows (1957) compared the performance of H1, S24, New Zealand perennial, Irish and Devon Eaver perennial ryegrass as single plants and in sown drills and broadcast plots, under two cutting regimes, viz. regular cutting (four times) and a hay plus aftermath cuts. Difference did occur in the rankings between the two years for which data are given, especially so with H1 which lost its superiority under spaced plant conditions when grown in the swards, an effect more in evidence in the second year. Devon Eaver and Irish usually ranked fourth or fifth; but another interaction involved New Zealand perennial which generally ranked higher in the swards than in the spaced plants.

Kelly (1958) found the relationship between sward and spaced plant performance of varieties of Dactylis glomerata to be of value only during the early spring. A somewhat similar conclusion with the same species was reached by Knight (1960) who showed that the correlation between plants under two spacing conditions (one foot by three feet and five inches by five inches) deteriorated as the swards aged. Part of the reason for this is because plants in the vegetative phase are affected differently by competition than plants in the reproductive stage.

Lazenby & Rogers (1960, 1962, 1964a, 1964b, 1965a, 1965b, 1965c) studied the performance of a number of ryegrass varieties at different spacings. The varieties included (although not all in the same experiment) S23, Irish, Kent, New Zealand perennial and S24 (of which seven clones were used in the one experiment), and the spacings varied between 27 by 27 inches and 3 by 3 inches. A closely sown broadcast plot was also included. While density-by-variety interactions occurred for yield and other characters, they were mainly due to the interaction between the widest spacing (27 by 27 inches) and the rest (9 by 9 inches, 3 by 3 inches and the broadcast plots). Lazenby & Rogers (loc.cit) concluded that, provided complete ground cover was achieved spaced plants could be used to assess sward performance. Presumably, at complete ground cover, competition for both nutrients and light was occurring in a similar fashion among spaced plants as within swards.

Lazenby & Rogers (1964c) found spaced plants (27 inches by 27 inches) produced relatively more of their annual yield in the last harvest (late autumn) than plants at close spacing (3 inches by 3 inches).

The effect of nitrogen was notable; the swards responded to applications up to 800 lb. N per acre, while the spaced plants failed to respond above 400 lb. This interpreted as being due to the spaced plants having access to a larger reservoir of soil nutrient per plant than the more closely spaced plants; in effect the spaced plants are in a higher fertility environment. A similar conclusion can be reached with soil moisture content.

While the spaced plants did have heavier tillers (Lazenby & Rogers, 1965a), the plasticity in yield per plant at different densities was associated with differences in tiller number (1964a). Density-by-genotype interactions for tiller weight were not significant.

Tiller number plasticity, rather than tiller weight plasticity, while a feature of ryegrass species under different levels of competition, is by no means the rule in the Gramineae. Phalaris coerulescens and Festuca arundinacea respond to reduced competition by producing more leaf area per tiller, rather than more tillers (Rhodes, 1968).

With Lolium species, Fejer (1959) found considerable variation between lines in tillering response to competition; some lines tended to reduce tiller weight with increasing competition, while other lines tended to reduce tiller number. This was the major source of genotype-by-competition interaction. Fejer's conclusions were that single spaced plants do not give precise information on the behaviour of the same plants under competitive conditions of varying severity.

Simulated Swards

If we accept that spaced plant assessment, as currently practised, does not adequately predict sward yield performance, then some technique needs to be developed that would subject plants to conditions similar to those in a sward, but at the same time allow them to retain their identity so that suitable selections can be made.

A suggestion along these lines has been put forward by Lazenby & Rogers (1964a). Thye propose that, provided there are no interactions between the growth rhythms of the selected lines when compared as spaced plants and as swards, then satisfactory prediction of relative sward performance could be made from any density, provided a complete ground cover was achieved.

Other attempts to subject plants to sward-like competition have usually been effected by simulating a sward. An example mentioned previously is Jenkin's (1931) "tiller-bed".

England (1967, 1968) has reported on the use of non-sward densities (suitable for simulated swards) in assessing yield performances of Italian ryegrass. Fourteen ryegrass populations were sown in swards, 3-inch spaced rows, 6-inch square plantings and 3-inch square plantings. The only planting method-by-variety interation occurred at one harvest and then only between the 3-inch square plantings and the 3-inch rows.

While these "tiller-beds" and broadcast plots do subject the plant to competition, this competition is between similar, if not identical, genotypes. Donald (1968) contrasts the growth of a plant in a mixed community where aggressive competition is an advantage, to the growth in a uniform community where, as it is now involved in mutual competition amongst equally aggressive neighbours, the growth of the crop as a whole is reduced. This suggests that genotypes should be subjected to competition from the genotypes they are likely to encounter after selection, be it from a wide range of genotypes, as in a mixed pasture, or from almost identical genotypes, as in some cereals.

Studies of competition between Lolium species have been reported by Charles (1964). In this experiment S23, S24 (both L. perenne) and S22 (L. multiflorum) were sown alone with clover, and in all possible combinations with each other, also with clover. When S22 was sown with clover and rotationally grazed, it dominated the sward for at least five years. Sown in a mixture with S23, S24 and clover and grazed as above, S22 at first dominated the sward but within three years had been practically eliminated. This shows that monoculture sward assessment can be misleading, and Charles (1966) stresses the need for the plant breeder to know more about the behaviour of cultivars in mixtures.

Keller (1946) developed a technique to subject plants to intra-and inter-specific competition by planting out genotypes according to a plan which allowed competition between two, three, four or five species. Spacings used were wide, i.e. 18 inches, but closer spacings, such as 12 inches, were suggested. The previously reviewed literature suggests strongly that even 12 inches is too large a spacing for satisfactory testing of genotypes.

More recently, Gardner (1960) developed a technique by which grasses of similar appearance can be positively identified when grown in an artificially constructed sward. A grid is constructed using steel rods to form a mesh of two-inch squares. This is laid on the ground and plants are placed in the centre of each square. Different coloured paints used on the wires surrounding each square identify the plant genotype planted therein.

A further advantage of this technique is that far less seed is needed to assess a genotype than would be the case with monoculture broadcast plots. Furthermore, the problems associated with breaking up tillers can be largely avoided (Fejer, 1958; Breese & Haywood, 1966).

Use of Gardner's technique was reported by Gardner & Hunt (1963). Three lines of perennial ryegrass, viz. Irish, New Zealand and S23, were sown using the grid. Plant survival in monoculture swards was in the order S23, New Zealand, Irish which was the order of their respective aggressiveness as assessed in mixtures. When the plants were sown in combination, plant survival and tiller number of the more aggressive line increased, while that of the less aggressive line decreased. Significant differences between the three lines tested were detected for yield (Gardner, pers. comm.); but more results of that study await publication.

The high density spacing of the simulated sward and the use of inter-genotype competition both develop a more sward-like environment under which forage plants may be tested for selection. The situation is still unnatural, however, and further aspects of environment, such as frequency of defoliation and level of fertility, need to be considered. The present experiment is not concerned with these and all the pertinent literature is not being reviewed. Lazenby & Rogers (1965c) have shown some aspects of cutting frequency-by-genotype interaction for dry matter yield in an experiment involving two tall fescue varieties (<u>Festuca arundinacea</u>) and S22 (<u>Lolium multiflorum</u>). The spacing between plants was two inches.

The effect of levelsnitrogen was investigated also by Lazenby & Rogers (1965b) on eight clones of <u>Lolium perenne</u>. While genotype-by-nitrogen level interaction occurred for dry matter yield for some harvests over two years, annual totals showed no evidence of such interactions.

It appears, therefore, that plants should be examined under conditions approximating their eventual use. Techniques exist that attempt to approximate sward conditions, but these require further investigation and development.

Natural selection within swards and in spaced-plant plots.

It is clear that line-by-spacing interactions frequently occur for vegetative yield. It is therefore probable that similar interactions occur for seed yield. If genotype-by-spacing interactions do occur for yield of viable seeds, then natural selection could change gene and genotype frequencies in a genetically variable population during the process of seed multiplication. Where distance between plants decreases in succeeding generations, this could conceivably result in changes in the characteristics of a selected population or variety.

Changes in plant characters in Lolium perenne during seed multiplication have been reported by a number of workers (e.g. Kelly & Boyd, 1966; Cooper, 1959), while others have shown no evidence of this (e.g. Gorman 1940). It appears that shift will be more likely and occur more strongly where seed is increased in an environment somewhat different from that of the origin of the seed (Kelly & Boyd, 1966). These reports are not concerned with differences in plant spacing, but do demonstrate first, that there is selection during seed multiplication (although this may be partially due to selection in the sward before harvesting) and secondly, that environment-by-genotype interactions occur during seed multiplication.

Rumball (1970) examined shift intype of "Grasslands Manawa) Short Rotation Ryegrass (Lolium perenne x multiflorum) over a number of generations. Seed of each consecutive generation was sown out in one season so that generations were compared simultaneously. Changes occurred in winter growth score, summer growth score, persistency and degree of aftermath heading; but the shift in the first generation of seed increase was in the reverse direction to that in later generations. The first multiplication of seed was effected by spaced plants, while all later multiplications were effected by sown swards. The seeds used for the first multiplication were derived from a glasshouse isolation polycross, which is a technique that typically produces small seeds. Rumball (pers. comm.) tentatively suggests that some "carry-over" effect could have operated here. Inbreeding depression is not substantiated by the changes in winter and summer growth scores which shift in reverse directions. A genotype-by-environment interaction could also have occurred, as the spaced-plant increase was laid down at Palmerston North in the North Island, while the other increases were carried out in the South Island. Because of these alternative explanations for this effect, the change in shift in the characters observed by Rumball could have been due to a spacing-by-genotype interaction.

Charles (1964) and Brougham & Harris (1968, 1967) have shown that genotypes vary in their ability to survive in a sward. Brougham & Harris (1968) produced evidence that differences in sward management favoured different genotypes. Selection for one or the other genotypes was often accompanied by a shift in a number of reproductive characters.

Fejer (1962) reported that selection for high vegetative yield in Lolium perenne resulted in a correlated response in seed weight and date of ear emergence. Pleiotrophy and linkage were discussed as alternative mechanisms for this phenomenon.

These reports show that survival or selection based on vegetative characters often result in changes in non-vegetative characters.

In this experiment one aim was to measure sward survival, sward seed protection, spaced plant survival, spaced plant seed production and spaced plant type, to show how various selection pressures may act upon different closely related families in a population of Lolium perenne x multiflorum.

The diallel cross.

A diallel cross is effected when a number of parents are mated in every possible combination, the analysis being carried out on the performance of the offspring which may or may not include the parents. Basically each parent should be a single homozygous genotype, but lines may be used instead of single parents, provided the lines are relatively more inbred that the population of offspring arising from the diallel cross. Offspring arising from selfed parents may be used, but this may give rise to bias (Fisher, see Griffing, 1956b).

Two basic methods are employed in the analysis of the diallel cross. The first method was initiated by Sprague & Tatum (1942) who expressed the performance of the progeny in terms of the "general combining ability" (GCA) and "specific combining ability" (SCA) of the parents. Sprague & Tatum (loc. cit.) defined these as follows: "The term 'general combining ability' is used to designate the average performance of a line in hybrid combination...The term 'Specific combining ability' is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved."

In all these analyses the GCA and SCA variance estimates apply only to a hypothetical randomly mating population from which the parents were derived by inbreeding randomly selected individuals. In this respect Eisenhart's (1947) Model II applies.

A generalised treatment of the diallel cross was given by Griffing (1956b) who presented alternative analyses enabling information to be obtained about the parents: whether they are considered as a random sample form some hypothetical parent population (Model II) or considered as the whole population about which estimates are to be made (Model I). Analyses are given for four experimental methods, viz. (1) parents, one set of F1's, and the other (reciprocal) F1's are included (all p^2 combinations with p parents); (2) parents and one set of F1's are included but reciprocals F1's are not ($\frac{1}{2}p(p + 1)$ combinations); (3) one set of F1's and reciprocals are included but not the parents ($p(p - 1)$ combinations); and (4) one set of F1's but neither parents nor reciprocal F1's are included ($\frac{1}{2}p(p - 1)$ combinations).

The GCA estimated is due to the additive portion of the genetic variance, while the SCA estimated is due to dominance and epistasis or non-additive genetic variance.

The other basic method of analysing the diallel cross is based on Mather's (1949) analysis of the offspring of all possible crosses between a set of parents. This was developed by Hayman (1954b) and Jinks (1954) since when it has undergone several modifications (see Hayman, 1960). (It will be referred to hereinafter as

the Hayman-Jinks method.)
Homozygous parents are used, although Dickinson & Jinks (1956) have extended the analysis include heterozygous parents.

The Hayman-Jinks analysis estimate the additive, dominance and epistatic genetic variances of the parent population, provided Eisenhart's Model II applies. Using this method, Jinks (1955) has shown that in a large number of instances, occurrences of "over-dominance" or "heterosis" could be attributed to epistasis. This has considerable importance for any breeder wanting to utilize "hybrid vigour".

The results of simulated computer programmes suggest, however, that correlated gene distributions can cause anomalies in the Hayman-Jinks model (Nassar, 1965).

Hayman (1954a) presents an analysis of variance for the diallel cross, to be used prior to using the Hayman-Jinks method. This analysis of variance is in many respects identical to Griffing's (1956b) method 1 model II analysis (parents and both F1's and reciprocals included).

Analyses of Lolium perenne diallel crosses have been reported by Torrie (1957) and Fejer (1958). Analyses were based on Kempthorne (1952), but GCA and SCA estimates followed Rojas & Sprague's (1952) modification of Sprague & Tatum's (1942) method.

The choice of the diallel cross in these investigations was because it provides the greatest amount of information from the parents used. Torrie (loc. cit) states that for a fixed number of parents the best theoretical estimates of combining ability are obtained by the diallel cross, but its use is limited to a few parents. Combining ability estimates of a parent depend on the other parents used and a small number of parents may give very inaccurate estimates.

Fejer (1958) used only four parents, while Torrie used five parents in one experiment and ten in another. Hayman (pers. comm.) has criticised the extrapolation of results from diallel analyses where fewer than ten parents are used.

The results of the above diallel analyses of ryegrass in terms of GCA and SCA for green weight are briefly as follows: In unselected material GCA is of most importance, while among parents previously selected for green weight, SCA is more important than GCA.

Fejer (1958) with _L. perenne_ and Anderson (1960) with _Trifolium pratense_ used the diallel analysis to obtain estimates of heritability - which may be defined as the ratio of genetic variance to total variance. Heritability estimates allow some idea to be obtained of the probable gain from further selection. Heritability estimates of green weight in _Lolium perenne_ were found by Fejer to be generally low (_circa_ 10% or less) except in the late spring-early summer growth of autumn-sown lines, which had an estimated heritability of _circa_ 20%. Heritability estimates have to be treated with considerable reserve, as the numerator of the expression

$$\text{Heritability} = \frac{\text{genetic variation}}{\text{genetic variation + environtmental variation}}$$

could include non-additive genetic variation, which would not necessarily be recovered in later generations or in other environments.

Lush (1949) has made the distinction between heritability in the broad sense,

$$H_b = \frac{\text{additive genetic variation + non-additive genetic variation}}{\text{total variation}}$$

and heritability in the narrow sense,

$$H_n = \frac{\text{additive genetic variance}}{\text{total variance}} .$$

Fejer (1958) gives alternative estimates of heritability where the non-additive genetic variance can be estimated. Anderson (loc. cit.) gives estimates of heritability in the narrow sense only.

Dickinson & Jinks' (loc. cit.) modification of the Hayman-Jinks method of analysis has been applied to a 7 x 7 diallel cross of _Lolium perenne_ by Breese (1960). The parents used included two highly bred lines, S24, which were shown by the analysis to be the most homozygous for dominant genes, thus showing the efficiency of the breeding techniques used for this variety. Epistatic effects were not shown to be present.

A more extensive diallel analysis of _L. perenne_ was employed by Beddows _et al_

(1962) in an 8 x 8 diallel. The crosses were repeated over three years during which the fall in self and cross fertilization strongly suggested cytoplasmic aging. The analysis used (the Hayman-Jinks method) unlike that of Breese (loc. cit.) included reciprocals and thus was capable of showing the presence of strong maternal effects on seedling leaf growth.

Haywood & Breese (1966, 1968) and Haywood (1967) used the analyses of Hayman (1954b) and Jinks (1964) for a diallel cross between ten natural populations of Lolium perenne. This, in contrast to the material used by Breese (1960), was not bred.

Seedling characters were found to be largely controlled by maternal effects. GCA, SCA and maternal effects of a number of reproductive characters (number of flowering plants, number of inflorescences and date of ear emergence) were highly significant. Productivity up to and including the first hay cut was markedly influenced by maternal effects.

Thomas (1967, 1969a, 1969b) used S23, Irish, Algerian, Lithuanian and New Zealand varieties of perennial ryegrass in a 6 x 6 diallel cross. The analysis used was that of Hayman (1954b) and Jinks (1954) with the modification suggested by Wearden (1964).

The analysis of population means revealed strong maternal effects in a number of early seedling growth characters. The only adult character measured, flowering time, was the only character not affected by maternal effects. The analysis of the coefficients of variation for three seedling characters showed no evidence of maternal influences. This infers that stability in these characters were not affected by any cytoplasmic influence. The analysis of four seedling characters suggested that the genetic-by-environment interaction was of chromosomal origin, while maternal effects, supposedly cytoplasmic, were constant over all environments.

A diallel cross was used in the present experiment first because "Grasslands" Division, D.S.I.R., required the information of "Ariki" ryegrass and secondly because interactions, such as those being sought between the experimental treatments, may not necessarily be associated with additive genetic variance.

The highly selected elite parents of a synthetic variety, such as "Grasslands"

Ariki" ryegrass cannot be considered a random sample from some hypothetical population, so only the Model I methods of analyses presented by Griffing (1956b) are appropriate.

CHAPTER II

Materials and Methods

The Area and the Fertiliser Used for the Experiment.

The land used is described as a Manawatu sandy loam with a pH 4.5. Lime ($CaCO_3$) had been previously applied at two tons per acre. Immediately prior to planting, three cwt. per acre of superphosphate (17% P as P_2O_5) and one cwt. per acre of muriate of potash (KCl) was applied and rotary-hoed in. In addition, two cwt. per acre of ammonium sulphate (20% N) was applied in June (six weeks after planting), and two cwt. of nitrolime (16%) was applied in October.

The Population

The parents chosen for this experiment were deliberately chosen, i.e., they were not randomly taken from some larger population. For this reason, the data are interpreted in terms of Eisenhart's Model I analysis (1947).

Ten parents were chosen, eight of which constitute the elite parents of the synthetic variety, 'Grasslands Ariki' Ryegrass, - Lolium [(multiflorum x perenne) x perenne] - (Barclay, 1963). These were selected for the experiment because information was required about the Ariki variety. Two more parents were included to allow a more accurate assessment of the genetic parameters to be made. These two were selected on the basis of their high score in the same ecperiments in which the elite parents were progeny-tested.

The parents used are listed in Table I:

Table I

Parent	Diallel parent number	Elite parents
N 167/ 80	1	+
N 188/130	2	+
N 195/ 91	3	+
N 198/ 95	4	+
N 200/111	5	
N 206/139	6	+
N 217/116	7	+
N 252/140	8	
N 295/109	9	+
N 296/140	10	+

Their genealogy is given in Fig. 1. Their offspring, referred to as "lines", are numbered 1 to 45. The respective parents for each line can be determined from Table II.

Table II

Enumeration of the Lines.

Parents	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9
2		10	11	12	13	14	15	16	17
3			18	19	20	21	22	23	24
4				25	26	27	28	29	30
5					31	32	33	34	35
6						36	37	38	39
7							40	41	42
8								43	44
9									45

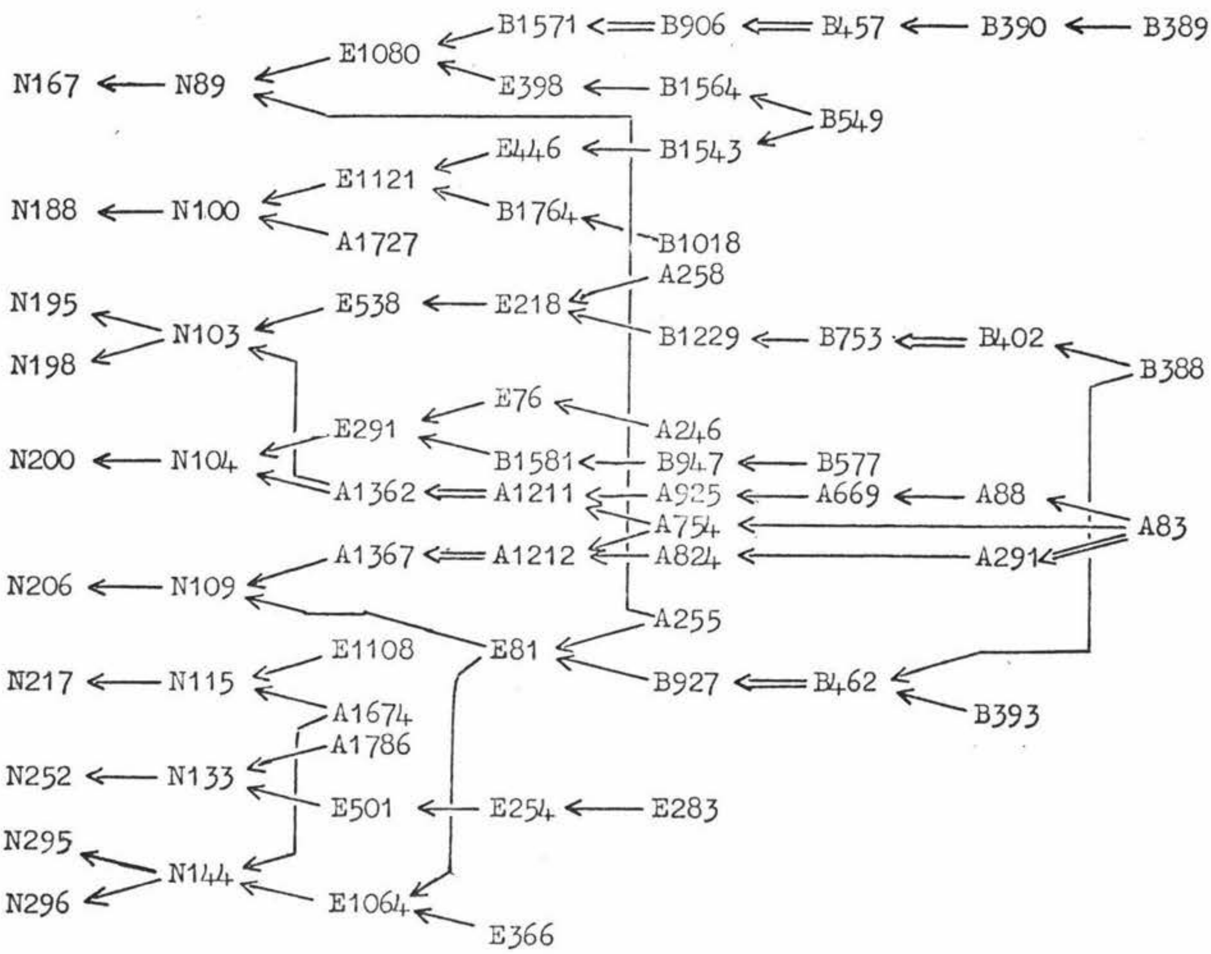
Thus line 33 is the offspring of parent 5 (N 200/111) and parent 8 (N 252/140).

Crossing techniques.

Crosses were effected in duplicate using the technique of mutual pollination under glassing bags, (Jenkin, 1931a, Beddows & Davis, 1938). The high self-incompatibility expressed by Lolium perenne (Jenkin, 1931b) also occurs in L. multiflorum and its hybrids (Barclay, pers. comm.), thus emasculation is superfluous. The humidity under glassing bags may have contributed towards the poor seed set achieved (Foster, 1968); a number of crosses yielded insufficient seed for the experiment and one cross produced only one seed. Missing plot values were later provided, as explained below, to complete the analyses.

Fig. 1.

Genealogy of the parents used in the diallel cross.



Key:- A = Lolium perenne
B = L. multiflorum
E = L. (multiflorum x perenne)
N = L. [(multiflorum x perenne) x perenne]

Arrows point from parent to offspring. Double shafted arrows indicate full-sib mating. Where a single parent is shown, the pollen parent is unknown but has usually been amoungst a number of known parents, such as in a polycross block. Every line of seed (for example, the seed from a parent plant in a polycross block) is given a number, the preceding letter indicating the species or subspecies. When the seeds of a line are planted out in the field, the resultant plants are also numbered. Thus N167/80 is interpreted as, "Ariki, line 167, plant number 80". In the earlier days at "Grasslands Division", D.S.I.R., line and plant numbers did not always have this relationship, hence the anomaly in the figure where line B462 is shown as being derived from plant B393.

The seed was harvested at the end of December 1967, dried and dressed. Since reciprocal crosses were not to be grown separately in the experiment, equal numbers of seeds from each parent were bulked where possible within each line.

Seeds of lines were germinated in petri dishes and planted in seedling flats in a glasshouse. After seven weeks, the seedlings were transplanted to the field site, where each line was grown under two spacing regimes. One of these spacings was representative of those commonly used by plant breeders at D.S.I.R. and other stations, viz, two feet by two feet. This will subsequently be referred to as the spaced plant treatment. The other, a narrow spacing, was an attempt to simulate plant densities approaching those found in ryegrass swards in this environment. A four inch by four inch spacing was chosen as a compromise between the higher densities expected in a sward and a density at which individual plants can still be recognised and measured. This will be subsequently referred to as the sward treatment.

Each of the ten replications is split for the treatments, each of which contains two randomly placed plants of each line; these two plants form a "plot".

The layout of the experiment is shown in Figs. 2, 3 and 4. Figs. 5 and 6 show the netting laid out prior to planting, and plants growing in the simulated sward, respectively.

<u>Harvesting</u>.

Harvests were taken on 19th September and 1st November in 1968, and on 29th January, 1970. At the first harvest only nine replications were used, while all ten replications were taken for subsequent harvests. At each harvest, plants were cut 1¼ inches above the ground level and the herbage from each

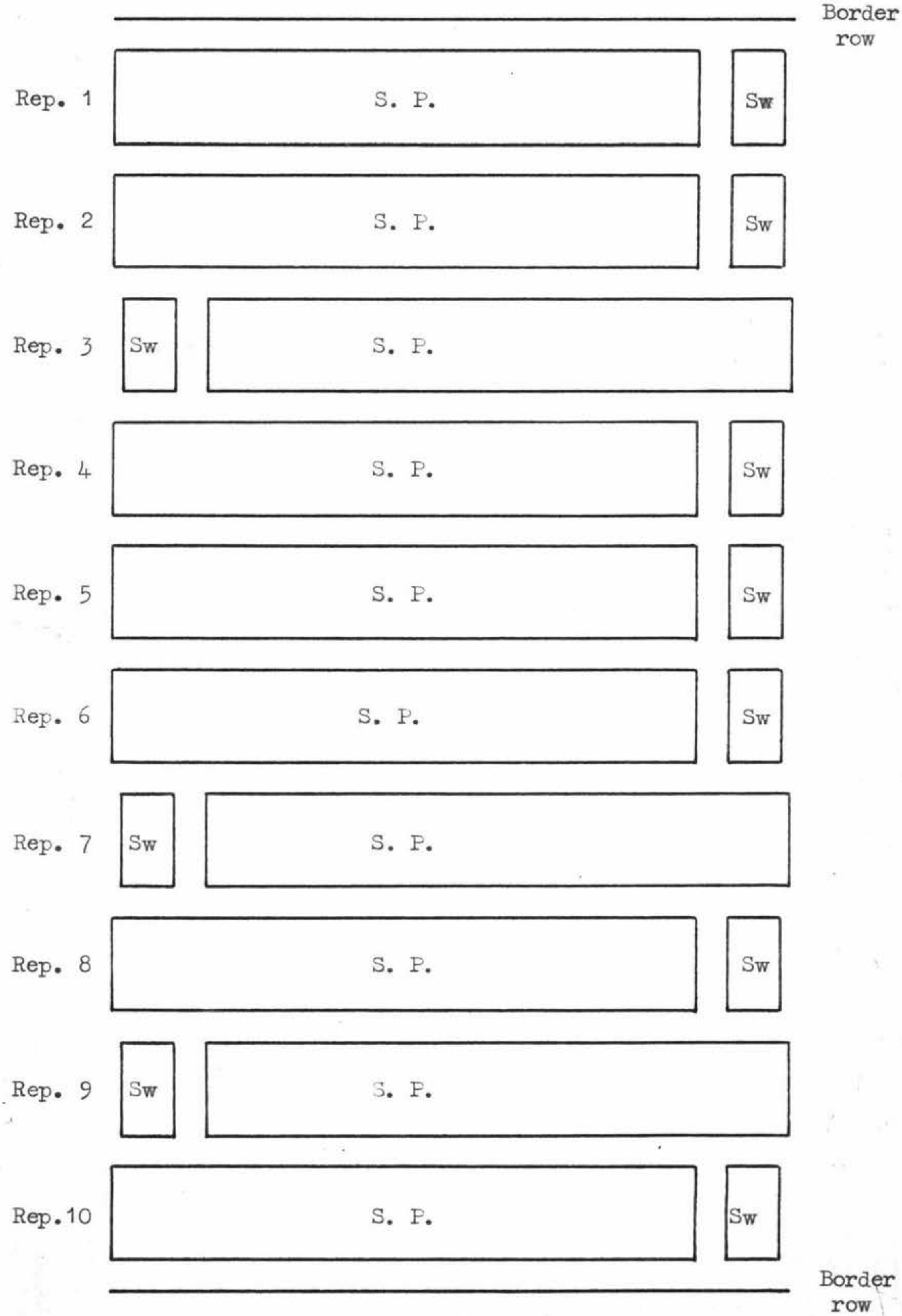


Fig. 2. Plan of the experiment.

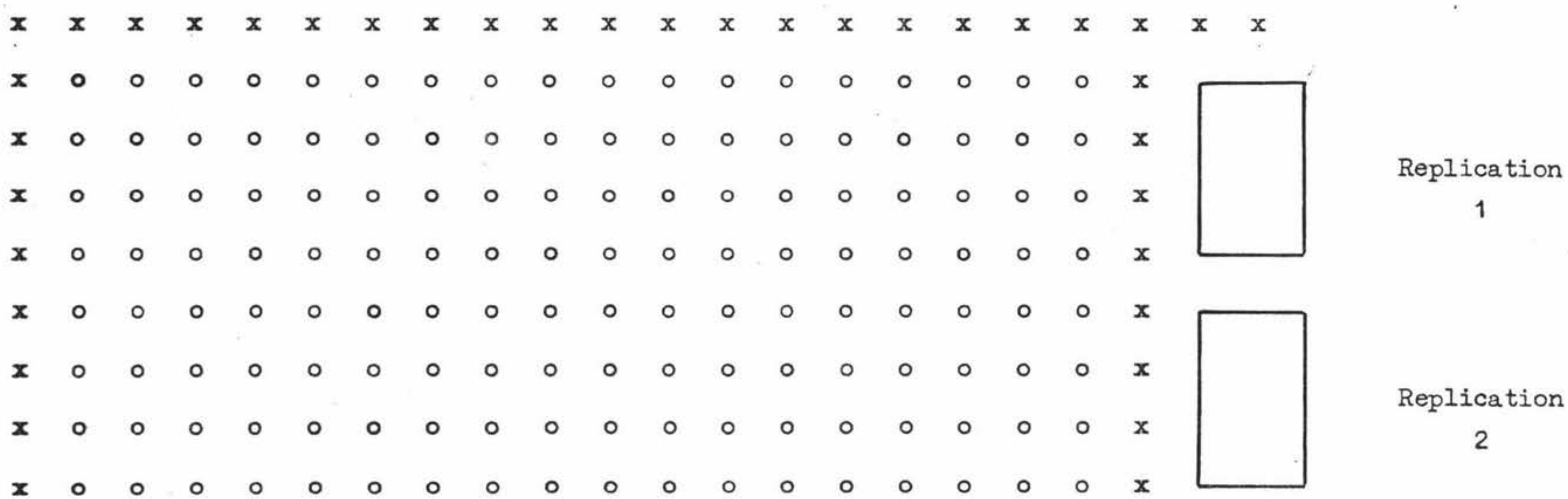
Scale: 1 inch = 10 feet.

S. P. indicates the spaced plant treatment

Sw indicates the sward treatment

Fig. 3.

Plan of the first two spaced plant treatment replications, showing sward treatments **and border** rows.



x indicates border plants

o indicates line plants

Scale: 1 inch = 6 feet.

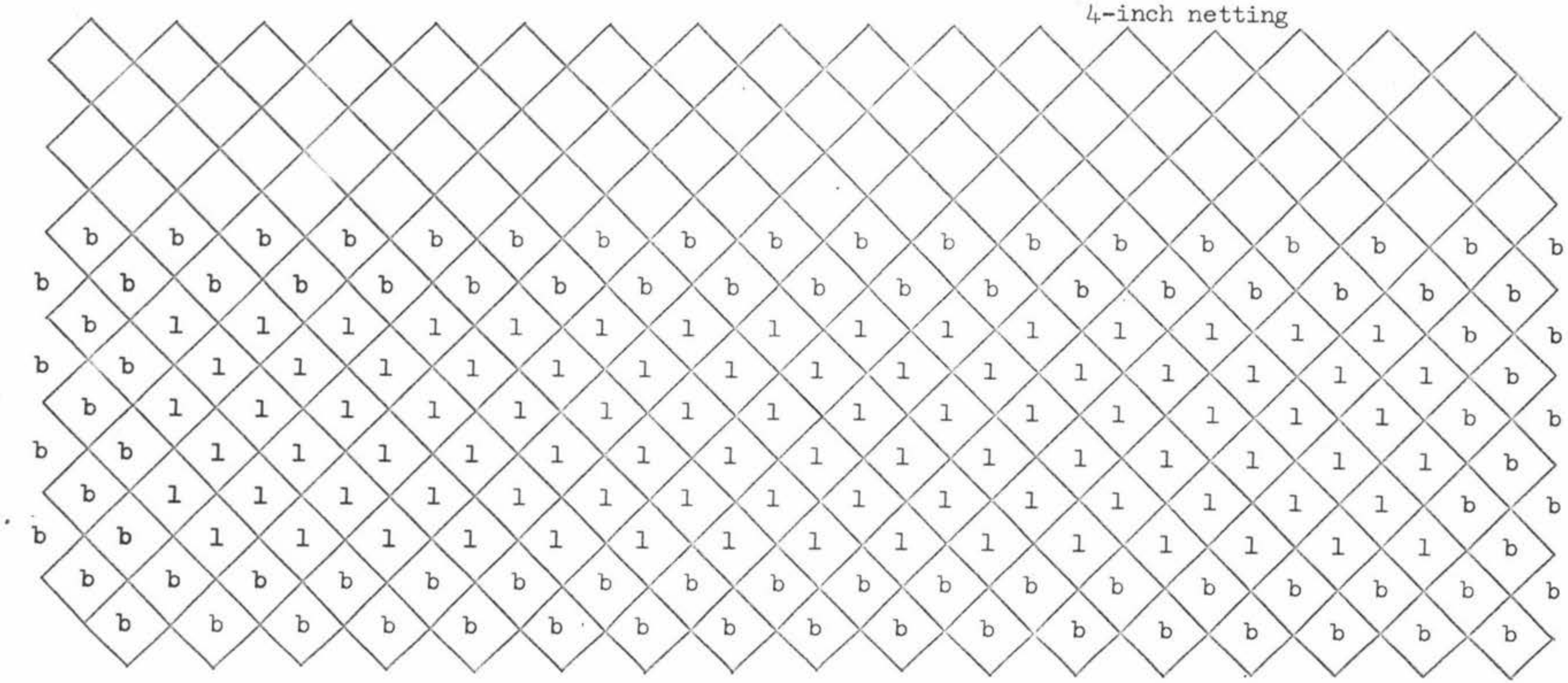


Fig. 4. Plan of simulated sward.
Scale: 1 inch = 1 foot.

b indicates border plant
l indicates line plant

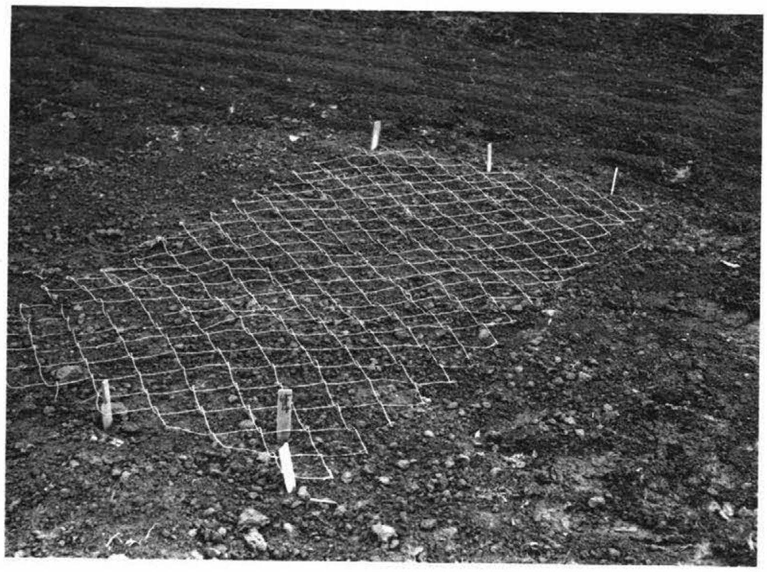


Fig. 5. Netting laid out prior to planting simulated sward.

Fig. 6. Close-up of plants growing in simulated sward.

plant was placed in a separate paper bag and transported inside to be weighed on balances previously tared so that they read nett plant weight. A number of plants were weighed, dried and re-weighed to assess dry matter percentage.

At the second harvest, tillers were counted on plants from three randomly chosen replications, viz, 3, 5 and 7; and at the final harvest, the numbers of fertile tillers were counted on all replications. The technique used for counting tillers was to proportion the plant either visually or by weight and count the number of tillers in the proportion. Where there appeared to be fewer than 100 tillers, the entire plant was counted.

At the final harvest, seeds were removed from the plants after a period of drying in a glasshouse, and weighed. The seed weight data are partly confounded by the occurrence of a severe outbreak of ergot (*Claviceps purpurea*). For this reason, 1,000-seed weight data are not included.

Plant type notes.

Type notes were made of the spaced plants for leaf width (visually scored 0-5), growth habit (0 = prostrate; 5 = erect), and after-math heading (number of heads).

Statistical analysis.

Transformations were not considered necessary for most of these data, consequently, all growth weight, seed weight and flowering time data analyses are performed on untransformed data. After-math heading data was, however, transformed using $x' = \sqrt{x + 1}$.

Growth productions are given in green weight, as the dry weight percentages estimates had large error terms. While the mean dry weight percentages did differ between harvests, the dry weight would have also differed with change in the time of harvest.

Fitting missing values.

Where only one plant of a line occurred in a treatment, its value was doubled for the plot total. Where both plants were missing as from the beginning of the experiment, plot values were fitted using the technique described by Yates (1933). The iterative procedure used to fit values to a large number of missing plots is tedious, but as no computer missing data program appeared to be available, a technique was developed which used a matrix inverting program. This is described in the appendix (q.v.).

Where an entire line was missing, viz, line 45, the analysis of variance was performed on the remaining 44 lines. The analysis of variance for the combining effects was completed by fitting a value to line 45 so that the specific combining ability (S.C.A.) mean square was at a minimum. This occurs when the S.C.A. effect for line 45 (i.e., between parents 9 and 10) is zero. One degree of freedom was removed from the S.C.A. degrees of freedom.

The combining ability analyses are performed on the line means, rather than on their totals. The total of the sums of squares for both combining ability effects in a complete diallel equals the line sums of squares in the analysis of variance. In these analyses, however, it was decided not to use this fitted line sums of squares in the analses of variance.

The line means of the plant green weight data are presented along with weighted least significant differences estimated by Tukey's method (see Scheffe, 1959). The New Range Test of Duncan (1955) appears to be invalid (Scheffe, loc. cit.). Steel & Torrie (1960) suggest that the 10% level is more appropriate than the 5% level for Tukey's Test.

The expectations for mean squares and the degrees of freedom are given in Tables III, IV and V. These are given for b replications, t treatments, l lines, c plants of each line per plot (i.e., per treatment in each replication) and p parents. The actual error degrees are reduced by the number of missing values. The error term in the entire experiment analysis is based on the plot totals. Table III is an extension of a table given by Anderson & Bancroft (1953); the line and treatment effects are considered to be fixed while the replication effects are considered to be random.

Tables IV and V are taken from Griffing (1956b). The line and replications effects are considered to be fixed. While a mixed model, presented by Griffing (loc. cit.) would be more appropriate (fixed line, random replication effects), the expectations of mean squares are based on arbitary assumptions and are not considered appropriate.

In the analyses of the data, the denominator for the F ratio is shown by an asterisk. Anderson & Bancroft (loc. cit.) point out the difficulty in obtaining an F ratio when the replication variance is significant. The Slatterwaite approximation (see Anderson & Bancroft, loc. cit.), however, gives an F ratio very similar to that obtained using the replication-by-treatment mean square as denominator, and the interaction degrees of freedom. Thus all F tests for treatment will use the interaction mean square as denominator.

As the time for the final cut approached, it was noticed that the growth of plants in the swards had become most uneven. In spite of the two rows of border plants, the outer rows of the simulated swards were growing more vigorously than the middle rows.

Previously, no note was made of the plant's position when green weights were made, and as the layout was randomised, it was often impossible to determine from which of two positions a particular value originated. Realizing this, I relabelled the bags so that each plant record could be compared with its position. As anticipated, analysis of the green weight data from the swards showed that both the plant and plot variances were too high to detect significant variances of any factor except that of treatment.

Table III

Expectations of mean squares for the entire experiment.

b replications, t treatments, and l lines.

Source of variance		Degrees of freedom	E(Mean square)
Replications	(R)	$(b - 1)$	$\sigma_e^2 + lt\sigma_b^2$
Treatments	(T)	$(t - 1)$	$\sigma_e^2 + l\sigma_{bt}^2 + lb\phi_t$
R x T		$(b - 1)(t - 1)$	$\sigma_e^2 + l\sigma_{bt}^2$
Lines	(L)	$(l - 1)$	$\sigma_e^2 + t\sigma_{bl}^2 + tb\phi_l$
L x R		$(l - 1)(b - 1)$	$\sigma_e^2 + t\sigma_{bl}^2$
L x T		$(l - 1)(t - 1)$	$\sigma_e^2 + b\phi_{tl}$
Error		$(l - 1)(b - 1)(t - 1)$	σ_e^2

Table IV

Expectations of mean squares for each treatment considered separately.

b replications, l lines, and c plants per plot.

Source of variance		Degrees of freedom	E(Mean square)
Lines	(L)	$(l - 1)$	$\sigma_e^2 + bc\phi_l$
Replications	(R)	$(b - 1)$	$\sigma_e^2 + lc\phi_b$
L x R		$(l - 1)(b - 1)$	$\sigma_e^2 + c\phi_{lb}$
Error		$lb(c - 1)$	σ_e^2

Table V

Expectations of mean squares for the combining effects.

p parents.

Source of variance	Degrees of freedom	E(Mean square)
General combining ability	$(p - 1)$	$\sigma_e^2 + (p - 1)[\frac{1}{p - 1}]\sum_i g_i^2$
Specific combining ability	$\frac{1}{2}p(p - 1)$	$\sigma_e^2 + [\frac{2}{p(p - 1)}]\sum_i \sum_j s_{ij}^2$
Error	m	σ_e^2

Error degrees of freedom, m, is the same as the error degrees of freedom in the analysis of variance.

To test G.C.A.-by-treatment interaction, an interaction mean square is obtained:

$$(I)MS = (G.C.A.)MS(\text{treatment } 1) + (G.C.A.)MS(\text{treatment } 2) - \tfrac{1}{2}(G.C.A.)MS(\text{general anaysis})$$

This is tested against the EMS for the general analysis of combining ability effects. (Hayman, pers. comm.)

Thus it was decided to employ an analysis of co-variance.

First a regression coefficient "b" was obtained of plant growth (y) on row position (x) in the sward. The value x is 1 for rows 1 and 6; 2 for rows 2 and 5; and 3 for rows 3 and 4. Professor Hayman advised me to use a value obtained over all replications.

The value "b" is obtained from:

$$b = \frac{\text{Covariance } (x:y_1)}{\text{Variance } (x)}$$

From this a set of weighted values are obtained to replace the raw data in the analysis, thus:

$$y_2 = (y_1 - bx)$$

where y_2 is the weighted value of plant growth

y_1 is the raw value of plant growth

b is the regression coefficient

x is the row position for y_1

Comparisons between the parental lines for the relationship between vegetative tiller number (measured in November) and fertile tiller number (January) are shown for each treatment. Similar relationships between green weight and tiller number (vegetative and fertile), seed weight and fertile tiller number, and green weight and plant position in the sward are also given. In the regression graphs, the dependent variables are shown covering the range of mean values obtained.

<u>Heritability estimates.</u>

Heritabilities in the narrow sense (Lush, 1949) are estimated using the technique reported by Gardner (1963).

$$H = \frac{4\sigma_g^2}{4\sigma_g^2 + 4\sigma_s^2 + \sigma_e^2}$$

where σ_g^2 is the G.C.A. variance

σ_s^2 is the S.C.A. variance, and

σ_e^2 is the error variance.

These are obtained from the expectations of mean squares of the analysis in Table VI.

In this analysis, it is assumed that the parents are randomly selected and are non-inbred. Failure of the first assumption invalidates the expectations of mean squares, while failure of the second biases the heritability estimates. The level of inbreeding in the population in this experiment affects the results only by about 2%. As it is superfluous to estimate heritabilities to three significant figures, this error is of no consequence. The population cannot be considered randomly selected, however, and the first assumption therefore fails, but in spite of this, the heritabilities are a standard by which ratios of additive genetic to phenotypic variance can be obtained, as well as possible gains from selection.

Table VI

Expectations of mean squares for the combining effects.

Source of variance		Degrees of freedom	E(Mean square)
Replications (R)		$(b - 1)$	
Lines (L)		$(l - 1)$	
	G.C.A.	$(p - 1)$	$\sigma_e^2 + cb\sigma_{bl}^2 + cb\sigma_s^2 + cb(p - 2)\sigma_g^2$
	S.C.A.	$\frac{1}{2}p(p - 3)$	$\sigma_e^2 + cb\sigma_{bl}^2 + cb\sigma_s^2$
R x L		$(l - 1)(b - 1)$	$\sigma_e^2 + cb\sigma_{bl}^2$
Error		$lb(c - 1)$	σ_e^2

where $l = \frac{1}{2}p(p - 1)$

Chapter Three.

Tables of Results and Analyses of Data.

Table VII

Average green weight (grms) per plant and rank for each line for the treatments separately and together. September harvest. The similarity of means of some lines is due to rounding-off.

Line	Spaced treatment mean	Spaced treatment rank	Sward treatment mean	Sward treatment rank	General mean	General rank
1	40	37	34	5	37	17
2	43	31	33	17	33	27
3	52	13	17	34	35	24
4	49	20	23	23	36	20
5	35	42	15	37	25	40
6	35	41	14	40	24	43
7	48	21	19	30	33	26
8	47	22	26	11	37	19
9	27	44	18	33	23	44
10	61	5	19	31	40	11
11	43	32	19	29	31	32
12	44	29	29	8	37	18
13	45	27=	20	28	32	29
14	36	40	23	18	30	33
15	50	17	21	26	35	22
16	56	7	32	7	44	6
17	46	24	24	15	35	23
18	42	33	14	38	28	37
19	41	35	8	44	25	42
20	40	38	14	41	27	39
21	44	30	24	14	34	25
22	45	26	14	39	29	35
23	54	12	39	3	46	3
24	54	11	33	6	44	7
25	62	3	22	25	42	10
26	49	18	17	35	33	28
27	67	1	23	19	45	5
28	57	6	28	9	43	9
29	49	19	26	12	37	15
30	47	23	24	13	36	21
31	45	25	18	32	32	30
32	50	16	41	1	46	4
33	45	27=	12	42	28	36
34	55	8	20	27	38	14
35	55	10	23	22	39	12
36	61	4	35	4	48	1
37	31	43	23	16	27	38
38	41	36	22	24	31	31
39	42	34	17	36	29	34
40	51	15	26	10	39	13
41	55	9	39	2	47	2
42	51	14	23	21	37	16
43	64	2	23	20	43	8
44	40	39	9	43	25	41
(45)	(51)		(29)		(40)	

Table VII (cont.)

		Spaced treatment	Sward treatment	General
Over-all mean		48	22	35
S.E. (Over-all mean)		1	1	1
S.E. (Line mean)		5	4	4
S.E. (Difference between line means)		7	6	5
Tukey's Test	10%	24	22	19
	5%	26	23	21
	1%	27	24	22

Table VIII

General analysis of variance for green weight. September harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	81,114	8	10,139	20.608	.001
Treatments	(T)	246,129	1	246,129	149.1	.001
R x T		13,205	8	1,651	* 3.355	.005
Lines	(L)	73,508	43	1,709	3.475	.001
L x R		158,383	344	460	0.936	NS
L x T		31,090	43	723	1.470	.05
Error		154,478	314	492	*	

Table IX

Analysis of variance for green weight (gms) in the spaced plant treatment.

September harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	41,204	8	5,151	9.546	.001
Lines	(L)	58,388	43	1,358	2.517	.001
R x L		177,507	329	540	1.400	.01
Error		122,130	317	385	*	

Table X

Analysis of variance for green weight (gms) in the sward treatment.

September harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	52,960	8	6,620	16.121	.001
Lines	(L)	46,060	43	1,071	2.601	.001
R x L		135,510	329	412	1.309	.05
Error		99,124	315	315	*	

Table XI

General analysis of variance of the combining effects for green weight. September harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	772	9	86.8	6.277	.001
Specific combining ability	1,295	34	38.1	2.786	.001
G.C.A.-by-treatment interaction		9	179.2	13.113	.001
Error		314	13.7	*	

Table XII

Analysis of variance for the combining effects for green weight. Spaced plant treatment. September harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	1,114	9	123.8	5.784	.001
Specific combining ability	2,142	34	63.0	2.943	.001
Error		317	21.4	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	12.8	16.9
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	41.6	54.9
σ_e^2	21.4	28.2
		100.0

Table XIII

Analysis of variance of the combining effects for green weight. Sward treatment. September harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	885	9	98.3	5.622	.001
Specific combining ability	1,709	34	50.3	2.875	.001
Error		315	17.5	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	10.1	16.7
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	32.8	54.3
σ_e^2	17.5	29.0
		100.0

Table XIV

G.C.A.'s and S.C.A. variances for green weight. September harvest.

Parent	Spaced plant treatment			Sward treatment		
(i)	g_i	Rank	$\sigma^2_{s_i}$	g_i	Rank	$\sigma^2_{s_i}$
1	-6.5	10	23	-2.7	8	26
2	-1.0	7	46	2.1	3	14
3	-0.9	6	47	-2.2	7	53
4	4.9	2	48	-1.7	6	8
5	2.2	4	11	-1.1	5	44
6	-5.2	9	38	-2.9	9	10
7	2.8	3	67	5.5	2	56
8	0.0	5	31	-3.7	10	23
9	5.3	1	15	6.4	1	17
10	-1.9	8	23	-0.7	4	22
S.E. (g_i)	1.6			1.3		
S.E. $(g_i - g_j)$	2.3			2.1		

Table XV

S.C.A.'s for each cross for green weight (gms). Spaced plant treatment. September harvest.

Parents	2	3	4	5	6	7	8	9	10
1	0.0	2.8	6.0	5.3	-1.1	-8.7	6.7	0.9	-11.9
2		14.8	-8.7	-4.4	3.1	-13.1	2.9	3.7	1.7
3			-10.1	-7.8	-2.0	-6.1	-2.4	1.4	9.3
4				7.1	1.6	12.1	4.7	-9.1	-3.7
5					0.6	-2.3	-5.3	0.3	6.6
6						15.6	-11.7	-7.3	1.1
7							0.2	-0.6	2.8
8								10.8	-5.9
9									-

S.E. (s_{ij}) = 4.1 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 6.1 $(i \neq j, k; j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 5.7 $(i \neq j, k, l; j \neq k, l; k \neq l)$

Table XVI

S.C.A.'s for each cross for green weight (gms). Sward treatment. September harvest.

Parents	2	3	4	5	6	7	8	9	10
1	10.8	4.9	-1.7	3.1	-3.2	-12.7	1.8	-1.1	-1.9
2		-3.7	-3.8	5.6	-1.9	-7.2	-0.2	0.8	-0.5
3			-4.6	-11.8	-4.1	-2.4	-3.2	12.0	13.0
4				1.6	-0.9	-3.5	10.8	-1.6	3.7
5					-0.6	14.0	-5.9	-7.7	1.7
6						10.0	7.1	-4.3	-2.0
7							1.6	4.7	-4.7
8								-2.7	-9.2
9									-

S.E. (s_{ij}) = 3.7 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 5.5 $(i \neq j, k; j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 5.1 $(i \neq j, k, l; j \neq k, l; k \neq l)$

Table XVII

Heritability estimates for green weight. September harvest.

Sward treatment $H = 0.05$

Spaced plant treatment $H = 0.06$

Table XVIII

Average green weight (gms) per plant and rank for each line for the treatments separately and together. November harvest.

Line	Spaced treatment mean	Spaced treatment rank	Sward treatment mean	Sward treatment rank	General mean	General rank
1	240	28	47	29	143	29
2	241	27	52	25	146	26
3	308	3	39	35	174	11
4	278	14	52	24	165	17
5	183	44	26	44	104	44
6	210	39	32	38	121	41
7	230	33	45	32	137	35
8	282	11	47	30	164	19
9	205	42	39	36	122	40
10	301	5	55	20	178	7
11	304	4	69	7	186	3
12	224	36	67	9	145	27
13	232	30	45	33	138	34
14	229	34	30	41	129	37
15	268	19	48	28	158	23
16	282	13	59	16	170	15
17	290	8	68	8	179	6
18	245	26	44	34	144	28
19	208	40	27	43	117	42
20	217	38	31	40	124	39
21	220	37	58	17	139	32
22	231	31	38	37	135	36
23	234	29	80	4	157	24
24	269	18	75	5	172	14
25	289	9	56	19	173	13
26	199	43	32	39	116	43
27	364	1	61	14	212	1
28	342	2	80	3	211	2
29	264	23	66	10	165	18
30	292	7	62	13	177	10
31	227	35	55	21	141	31
32	274	15	86	2	180	4
33	273	16	47	31	160	21
34	282	12	65	11	173	12
35	265	21	56	18	161	20
36	265	20	54	22	160	22
37	230	32	52	23	141	30
38	206	41	50	27	128	38
39	247	25	52	26	149	25
40	273	17	59	15	166	16
41	265	22	90	1	177	9
42	292	6	63	12	178	8
43	289	10	70	6	179	5
44	248	24	29	42	139	33
(45)	(273)		(72)		(172)	

Table XVIII (cont.)

		Spaced treatment	Sward treatment	General
Over-all mean		258	54	156
S.E. (Over-all mean)		3	1	2
S.E. (Line mean)		21	9	11
S.E. (Difference between line means)		29	13	16
Tukey's Test	10%	108	49	60
	5%	114	51	62
	1%	120	54	65

Table XIX

General analysis of variance for green weight (gms). November harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	632,190	9	70,243	14.427	.001
Treatments	(T)	18,262,907	1	18,262,907	327.8	.001
R x T		501,475	9	55,719	* 11.44	.001
Lines	(L)	1,029,481	43	23,941	3.030	.001
R x L		3,058,021	387	7,502	1.623 *	.005
T x L		453,775	43	10,553	2.167	.005
Error		1,723,749	354	4,869	*	

Table XX

Analysis of variance for green weight (gms) in the spaced plant treatment. November harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	1,096,646	9	121,850	14.445	.001
Lines	(L)	1,266,498	43	29,453	3.492	.001
R x L		4,062,855	370	10,981	1.302	.05
Error		3,137,980	372	8,435	*	

Table XXI

Analysis of variance for green weight (gms) in the sward treatment. November harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	37,019	9	4,113	2.409	.05
Lines	(L)	216,758	43	5,041	2.952	.001
R x L		718,915	370	1,943	1.138	NS
Error		601,070	352	1,708	*	

Table XXII

General analysis of variance of the combining effects for green weight. November harvest.

Source of variation	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	12,770	9	1,418.9	11.656	.001
Specific combining ability	13,242	34	389.5	3.199	.001
G.C.A.-by-treatment interaction		9	3,177.6	26.110	.001
Error		354	121.7	*	

Table XXIII

Analysis of variance of the combining effects for green weight. Spaced plant treatment. November harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	30,358	9	3373.1	7.997	.001
Specific combining ability	33,202	34	976.5	2.315	.001
Error		372	421.8	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	369	27.4
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	555	41.2
σ_e^2	422	31.4
		100.0

Table XXIV

Analysis of variance for the combining effects for green weight. Sward treatment. November harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	4625	9	513.9	6.019	.001
Specific combining ability	6534	34	192.2	2.251	.005
Error		352	85.4	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	53.6	21.8
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	106.8	43.5
σ_e^2	85.4	34.7
		100.0

Table XXV

G.C.A.'s, and S.C.A. variances for green weight. November harvest.

Parent	Spaced plant treatment			Sward treatment		
(i)	g_i	Rank	$\sigma^2_{s_i}$	g_i	Rank	$\sigma^2_{s_i}$
1	-18	8	657	-13.3	10	12
2	6	6	553	0.3	6	102
3	-19	9	555	-3.3	8	158
4	36	1	1107	3.0	5	69
5	0	7	196	3.0	4	127
6	-39	10	389	-11.2	9	0
7	9	2	854	6.0	2	168
8	8	3	28	-2.3	7	142
9	7	5	120	13.9	1	23
10	8	4	151	3.8	3	86
S.E. (g_i)	7			3.1		
S.E. $(g_i - g_j)$	10			4.6		

Table XXVI

S.C.A.'s of each cross for green weight (gms). Spaced plant treatment. November harvest.

Parents	2	3	4	5	6	7	8	9	10
1	-7	20	32	38	-19	-39	-19	35	-43
2		56	4	-41	7	-45	-4	11	18
3			-30	-31	17	-28	-16	-12	22
4				-5	-55	61	40	-37	-10
5					8	7	7	17	-1
6						37	3	-20	21
7							-2	-10	18
8								16	-26
9									-

S.E. (s_{ij}) = 18 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 27 $(i \neq j, k;\ j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 25 $(i \neq j, k, l;\ j \neq k, l;\ k \neq l)$

Table XXVII

S.C.A.'s of each cross for green weight (gms). Sward treatment. November harvest.

Parents	2	3	4	5	6	7	8	9	10
1	6.1	14.5	-4.3	8.6	-3.5	-14.5	6.5	-8.1	-5.3
2		4.4	12.0	9.7	1.7	-30.3	-3.8	-9.5	9.7
3			-10.0	-26.6	-8.4	1.3	-10.6	15.0	20.3
4				-4.2	-13.9	-1.8	25.4	-4.9	1.7
5					8.8	22.6	-8.2	-6.2	-4.6
6						5.4	11.9	-6.9	4.9
7							1.1	16.4	-0.3
8								4.1	-26.4
9									-

S.E. (s_{ij}) = 8.1 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 12.2 $(i \neq j, k;\ j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 11.3 $(i \neq j, k, l;\ j \neq k, l;\ k \neq l)$

Table XXVIII

Heritability estimates for green weight. November harvest.

Sward treatment H = 0.07

Spaced plant treatment H = 0.11

Table XXIX

Average green weight (gms) per plant and rank for each line for the treatments separately and together. January harvest. (Sward data are weighted for all analyses.)

Line	Spaced treatment mean	Spaced treatment rank	Sward treatment mean	Sward treatment rank	General mean	General rank
1	553	29	54	29	303	28
2	606	23	77	8	342	19=
3	675	12	39	43	357	16
4	656	14=	52	30	354	17
5	369	44	41	41	205	44
6	613	21	41	40	327	24
7	513	37	61	24	287	36
8	705	8	73	13=	389	8
9	551	30=	49	32	300	31
10	773	3	69	17	421	3
11	656	14=	75	10	365	13=
12	467	41	78	6	272	40
13	541	32	49	33	295	33
14	473	40	28	44	250	42
15	502	38	48	34	275	38
16	706	7	71	15	388	9
17	639	17	76	9	358	15
18	615	20	68	18	342	19=
19	448	42	39	42	244	43
20	529	35	42	38	286	37
21	598	24	61	22	330	23
22	497	39	51	31	274	39
23	427	43	108	1	267	41
24	676	11	89	4	382	10=
25	566	27	64	21	315	26
26	551	30=	55	28	303	28=
27	798	2	61	23	429	2
28	664	13	73	13=	369	12
29	712	6	78	7	395	7
30	740	4	74	11	407	4
31	523	36	56	25	290	34
32	694	10	70	16	382	10=
33	632	18	44	37	338	21
34	721	5	83	5	402	5
35	620	19	66	19	343	18
36	558	28	46	35	302	39
37	535	34	41	39	288	35
38	540	33	55	26	298	32
39	610	22	64	20	337	22
40	592	25	55	27	323	25
41	695	9	97	2	396	6
42	812	1	74	12	443	1
43	640	16	91	3	365	13=
44	569	26	45	36	307	27
(45)	(717)		(94)		(405)	

Table XXIX (cont.)

		Spaced treatment	Sward treatment	General
Over-all mean		606	63	334
S.E. (Over-all mean)		7	1	3
S.E. (Line mean)		45	11	23
S.E. (Difference between line means)		64	16	33
Tukey's Test	10%	239	58	121
	5%	253	62	128
	1%	281	69	142

Table XXX

General analysis of variance for green weight (gms). January harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	2,159,509	9	239,945	11.335	.001
Treatments	(T)	125,670,989	1	125,670,989	202.2	.001
R x T		5,570,805	9	618,978	* 29.241	.001
Lines	(L)	5,013,473	43	116,592	4.065	.001
L x R		11,101,101	387	28,685	1.355 *	.05
L x T		7,159,532	43	166,501	7.864	.001
Error		7,451,170	352	21,168	*	

Table XXXI

Analysis of variance for green weight (gms) for the spaced plant treatment. January harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	4,323,676	9	480,408	11.628	.001
Lines	(L)	8,561,346	43	199,101	4.819	.001
R x L		21,142,930	369	57,298	1.387	.05
Error		14,005,844	339	41,315	*	

Table XXXII

Analysis of variance for green weight (gms) for the sward treatment. January harvest.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	55,828	9	6,203	2.516	.01
Lines	(L)	260,852	43	6,066	2.461	.001
R x L		760,149	370	2,055	0.832	NS
Error		852,923	346	2,465	*	

Table XXXIII

General analysis of variance of the combining effects for green weight. January harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	64,073	9	7,119	13.453	.001
Specific combining ability	66,425	34	1,954	3.692	.001
G.C.A.-by-treatment interaction		9	18,968	35.843	.001
Error		352	529	*	

Table XXXIV

Analysis of variance of the combining effects for green weight. Spaced plant treatment. January harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	194,642	9	21,627	10.469	.001
Specific combining ability	245,960	34	7,234	3.502	.001
Error		339	2,066	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	2,445	25.3
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	5,168	53.4
σ_e^2	2,066	21.3
		100.0

Table XXXV

Analysis of variance of the combining effects for green weight. Sward treatment. January harvest.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P <
General combining ability	8,106	9	901	7.307	.001
Specific combining ability	5,948	34	175	1.419	NS
Error		346	123.3	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	97.2	35.7
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	51.7	19.0
σ_e^2	123.3	45.3
		100.0

Table XXXVI

G.C.A.'s, and S.C.A. variances for green weight. January harvest.

Parent	Spaced plant treatment			Sward treatment		
(i)	g_i	Rank	$\sigma^2_{s_i}$	g_i	Rank	$\sigma^2_{s_i}$
1	-27	7	3543	-9.7	9	31
2	-18	6	10040	-2.1	6	93
3	-36	8	11697	4.9	3	116
4	65	1	420	2.6	4	-10
5	-16	5	5231	-1.7	5	78
6	-87	10	1352	-14.6	10	-39
7	47	4	4049	-4.0	7	60
8	-39	9	573	-6.9	8	42
9	51	3	5188	23.2	1	43
10	60	2	1320	8.3	2	-3
S.E. (g_i)	15			3.7		
S.E. $(g_i - g_j)$	23			5.6		

Table XXXVII

S.C.A.'s of each cross for green weight (gms). Spaced plant treatment. January harvest.

Parents	2	3	4	5	6	7	8	9	10
1	-8	63	30	93	-123	-14	-28	75	-88
2		221	2	-105	41	-162	-47	67	-8
3			-21	106	46	-20	-34	-195	45
4				89	-33	79	31	-10	9
5					20	57	81	80	-30
6						-8	56	-30	31
7							-23	-9	99
8								22	-58
9									-

S.E. (s_{ij}) = 40 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 60 $(i \neq j, k;\ j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 56 $(i \neq j, k, l;\ j \neq k, l;\ k \neq l)$

Table XXXVIII

S.C.A.'s of each cross for green weight (gms). Sward treatment. January harvest.

Parents	2	3	4	5	6	7	8	9	10
1	3.1	19.1	-17.2	0.7	2.2	-8.0	14.9	-2.8	-12.0
2		3.4	11.5	19.4	2.6	-28.6	-5.5	-13.1	7.2
3			-2.2	-27.0	-11.0	-2.3	-10.0	17.0	12.9
4				-0.2	3.8	2.7	14.9	-10.7	0.3
5					9.3	13.0	-10.3	-1.5	-3.6
6						1.6	-0.2	15.9	7.5
7							3.1	14.8	6.8
8								12.1	-19.0
9									-

S.E. (s_{ij}) = 9.8 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 14.7 $(i \neq j, k;\ j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 13.6 $(i \neq j, k, l;\ j \neq k, l;\ k \neq l)$

Table XXXIX

Heritability estimates for green weight. January harvest.

Sward treatment H = 0.12

Spaced plant treatment H = 0.11

Table XI

Average seed production (gms) per plant and rank for each line for the treatments separately and together. (Sward data are weighted for all analyses.)

Line	Spaced treatment mean	Spaced treatment rank	Sward treatment mean	Sward treatment rank	General mean	General rank
1	30.3	19	2.35	28	16.3	20
2	35.0	10	3.58	7	19.3	9
3	31.7	13	1.90	35	16.8	16
4	35.2	9	2.43	25	18.8	10
5	20.9	39	1.49	43	11.2	39
6	40.2	5	2.36	27	21.3	5
7	22.2	34	3.06	13	12.6	34
8	31.2	16	1.88	36	16.5	17
9	28.0	22	2.11	30	15.0	23
10	33.2	11	2.90	17	18.0	11
11	36.2	7	2.95	16	19.6	7
12	30.6	18	3.96	2	17.3	14
13	22.0	36	2.23	29	12.1	36
14	28.8	21	1.26	44	15.1	22
15	16.6	41	1.77	38	9.2	41
16	27.6	24	3.77	4	15.7	21
17	35.8	8	3.17	10	19.5	8
18	23.8	32	2.80	21	13.3	32
19	13.4	43	1.38	43	7.4	43
20	22.9	33	1.73	39	12.3	35
21	40.7	4	2.88	19	21.8	4
22	8.7	44	2.02	32	5.4	44
23	21.7	37	4.38	1	13.1	33
24	37.8	6	3.49	9	20.6	6
25	26.5	26	2.39	26	14.4	28
26	27.7	23	2.02	33	14.9	24
27	45.1	2	2.50	23	23.8	2
28	25.0	30	2.95	15	13.9	30
29	25.9	28	3.63	5	14.8	26
30	27.0	25	2.64	22	14.8	25
31	25.8	29	2.86	20	14.3	29
32	46.9	1	3.90	3	25.4	1
33	17.5	40	1.77	37	9.6	40
34	32.9	12	3.06	12	18.0	12
35	31.6	14	2.49	24	17.0	15
36	31.1	17	1.97	34	16.5	18
37	22.2	35	1.55	40	11.9	37
38	21.0	38	2.09	31	11.5	38
39	26.3	27	2.99	14	14.6	27
40	24.1	31	2.89	18	13.5	31
41	31.4	15	3.58	8	17.5	13
42	43.3	3	3.59	6	23.4	3
43	29.5	20	3.15	11	16.3	19
44	16.1	42	1.52	41	8.8	42
(45)	(30.4)		(3.52)		(16.9)	

Table XL (cont.)

		Spaced treatment	Sward treatment	General
Over-all mean		28.5	2.64	15.6
S.E. (Over-all mean)		0.4	0.08	0.3
S.E. (Line mean)		3.0	0.52	2.8
S.E. (Difference between line means)		4.2	0.73	5.7
Tukey's Test	10%	15.7	2.74	8.8
	5%	16.6	2.90	9.4
	1%	17.5	3.04	9.8

Table XLI

General analysis of variance for seed production (gms).

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio			P<
Replications	(R)	8,272	9	919.2		8.106		.001
Treatments	(T)	293,107	1	293,107	327.8			.001
R x T		8,047	9	894.1	*	7.886		.001
Lines	(L)	32,024	43	744.7			6.343	.001
L x R		43,421	370	117.4		1.035	*	NS
L x T		26,955	43	626.9		5.529		.001
Error		41,946	370	113.4		*		

Table XLII

Analysis of variance for seed production in the spaced plant treatment.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	16,262	9	1,807	10.129	.001
Lines	(L)	58,447	43	1,359	7.619	.001
R x L		83,578	370	226	1.266	.05
Error		62,259	349	178	*	

Table XLIII

Analysis of variance for seed production in the sward treatment.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	57.2	9	6.360	1.173	NS
Lines	(L)	531.1	43	12.351	2.278	.005
R x L		1,789.4	370	4.836	0.892	NS
Error		1,919.8	354	5.423	*	

Table XLIV

General analysis of variance of the combining effects for seed production.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	461.8	9	51.31	18.104	.001
Specific combining ability	340.8	34	10.02	3.536	.001
G.C.A.-by-treatment interaction		9	167.54	59.118	.001
Error		370	2.83	*	

Table XLV

Analysis of variance of the combining abilities for seed production. Spaced plant treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	1,729	9	192.19	21.54	.001
Specific combining ability	1,197	34	35.19	3.95	.001
Error		349	8.92	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	22.9	39.4
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	26.3	45.2
σ_e^2	8.9	15.4
		100.0

Table XLVI

Analysis of variance of the combining effects for seed production. Sward treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	9.370	9	1.041	3.840	.001
Specific combining ability	17.968	34	0.529	1.950	.01
Error		354	0.271	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	0.096	15.4
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	0.257	41.2
σ_e^2	0.271	43.4
		100.0

Table XLVII

G.C.A.'s, and variances of S.C.A. for seed production.

Parent	Spaced plant treatment			Sward treatment		
(i)	g_i	Rank	$\sigma^2_{s_i}$	g_i	Rank	$\sigma^2_{s_i}$
1	2.3	3	7	-0.33	8	0.3
2	0.6	5	18	0.08	5	0.3
3	-2.4	8	51	0.18	3	0.4
4	1.6	4	12	0.00	7	-0.1
5	0.5	6	31	0.06	6	0.5
6	-4.6	9	6	-0.61	10	0.0
7	9.4	1	29	0.14	4	0.3
8	-9.3	10	33	-0.39	9	0.2
9	-0.6	7	18	0.66	1	0.1
10	2.5	2	17	0.22	2	0.1
S.E. (g_i)	1.0			0.18		
S.E. ($g_i - g_j$)	1.5			0.26		

Table XLVIII

S.C.A.'s of each cross for seed production (gms). Spaced plant treatment.

Parents	2	3	4	5	6	7	8	9	10
1	-1.1	6.6	-0.6	3.9	-5.4	0.0	0.8	1.0	-5.3
2		6.5	5.5	1.1	-2.5	-9.7	-3.2	-0.9	4.2
3			-3.8	-13.2	1.4	5.2	-8.1	-3.8	9.2
4				-4.1	2.2	5.6	4.2	-3.6	-5.5
5					1.4	8.5	-2.2	4.5	0.1
6						-2.2	7.6	-2.4	-0.1
7							-4.5	-5.9	2.9
8								10.9	-5.6
9									-

S.E. (s_{ij}) = 2.6 $(i \neq j)$

S.E $(s_{ij} - s_{ik})$ = 4.0 $(i \neq j, k; j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 3.7 $(i \neq j, k, l; j \neq k, l; k \neq l)$

Table XLIX

S.C.A.'s of each cross for seed production (gms). Sward treatment.

Parents	2	3	4	5	6	7	8	9	10
1	-0.04	1.09	-0.41	0.06	-0.22	-0.10	1.14	-1.09	-0.42
2		0.05	0.23	1.19	0.12	-1.61	-0.57	0.39	0.24
3			-0.02	-1.50	-0.48	-0.08	-0.41	0.90	0.45
4				-0.31	-0.02	-0.29	0.70	0.33	-0.22
5					0.77	1.06	-0.54	-0.30	-0.43
6						-0.21	-0.10	-0.61	0.74
7							0.50	0.13	0.59
8								0.24	-0.95
9									-

S.E. (s_{ij}) = 0.46 $(i \neq j)$

S.E. $(s_{ij} - s_{ik})$ = 0.69 $(i \neq j, k; j \neq k)$

S.E. $(s_{ij} - s_{kl})$ = 0.64 $(i \neq j, k, l; j \neq k, l; k \neq l)$

Table L

Heritability estimates for seed production.

Sward treatment H = 0.04

Spaced plant treatment H = 0.22

Table LI

Date flowering commenced.

	Spaced treatment	Sward treatment	General
Mean date flowering commenced	13th December	27th December	20th December
S.E. (Date)	0.02	0.03	0.01

Table LII

General analysis of variance for day flowering commenced.

Source of variance	Sums of squares	Degrees of freedom	Mean square		F ratio	P<
Replications (R)	600.9	9	66.77		2.595	.05
Treatments (T)	78,658.4	1	78,658.4	972.5		.001
R x T	728.0	9	80.88	*	3.144	.01
Lines (L)	4,272.4	43	99.36		3.862	.001
L x T	2,933.8	43	68.23		2.652	.001
L x R	8,915.2	387	23.04		0.896	NS
Error	8,695.1	338	25.73		*	

Table LIII

Analysis of variance for day flowering commenced in the spaced plant treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications (R)	132.1	9	14.68	0.931	NS
Lines (L)	3,758.7	43	87.41	5.542	.001
R x L	5,995.9	370	16.21	1.027	NS
Error	5,615.5	356	15.77	*	

Table LIV

Analysis of variance for day flowering commenced in the sward treatment.

Source of variance	Sums of squares	Degrees of Freedom	Mean square	F ratio	P<
Replications (R)	1,101.4	9	122.38	4.275	.001
Lines (L)	3,472.3	43	80.75	2.829	.001
R x L	12,209.2	356	34.30	1.198	NS
Error	7,700.5	269	28.63	*	

Table LV

General analysis of variance of the combining effects for day flowering commenced.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	56.139	9	6.238	9.699	.001
Specific combining ability	51.618	34	1.518	2.361	.001
G.C.A.-by-treatment interaction		9	16.100	25.034	.001
Error		338	0.6431	*	

Table LVI

Analysis of variance of the combining effects for day flowering commenced. Spaced plant treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	128.75	9	14.305	18.138	.001
Specific combining ability	59.38	34	1.746	2.214	.001
Error		356	0.7887	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	1.689	49.2
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	0.957	27.9
σ_e^2	0.789	22.9
		100.0

Table LVII

Analysis of variance of the combining effects for day flowering commenced. Sward treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
General combining ability	44.32	9	4.924	3.440	.001
Specific combining ability	130.52	34	3.839	2.682	.001
Error		269	1.431	*	

Components of mean squares.

Item	Numerical value	Percent value
$\frac{1}{9}\sum_{i} g_i^2$	0.437	10.2
$\frac{1}{35}\sum_{i,j} s_{ij}^2$	2.408	56.3
σ_e^2	1.431	33.5
		100.0

Table LVIII

G.C.A.'s, and S.C.A. variances for day flowering commenced.

Parent (i)	Spaced plant treatment g_i	Rank	$\sigma^2_{s_i}$	Sward treatment g_i	Rank	$\sigma^2_{s_i}$
1	1.57	2	1.6	-0.24	6	-0.03
2	1.87	1	0.9	0.81	3	1.14
3	-1.08	8	0.1	-1.34	10	1.10
4	1.09	3	0.6	-0.45	7	1.38
5	-1.98	10	-0.1	0.26	4	4.39
6	-1.67	9	2.0	-0.56	8	4.55
7	0.31	5	0.40	0.23	5	-0.39
8	-0.56	7	1.6	0.89	2	2.69
9	-0.31	6	0.56	-0.68	9	3.90
10	0.75	4	0.3	1.08	1	-0.07
S.E. (g_i)	0.30			0.40		
S.E. $(g_i - g_j)$	0.44			0.60		

Table LIX

Analysis of variance, and G.C.A.'s for after-math heading. Spaced plant treatment.

Source of variance		Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications	(R)	1,073,678	9	119,298	1.356	NS
Lines	(L)	26,053,126	43	605,887	6.889	.001
Error		32,191,712	366	87,956	*	

Parent (i)	g_i	Rank
1	27	5
2	-46	8
3	35	4
4	-28	7
5	-70	9
6	89	2
7	184	1
8	-107	10
9	-27	6
10	58	3
S.E. (g_i)	21	
S.E. ($g_i - g_j$)	33	

Table LX

Analysis of variance, and G.C.A.'s for leaf-width. Spaced plant treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications (R)	32.84	9	3.649	5.465	.001
Lines (L)	239.59	43	5.572	8.346	.001
Error	247.66	371	0.6676	*	

Parent (i)	g_i	Rank
1	-0.024	7
2	-0.343	10
3	0.026	6
4	0.176	3
5	0.076	4
6	0.045	5
7	-0.199	8
8	0.308	1
9	0.226	2
10	-0.293	9
S.E. (g_i)	0.061	
S.E. $(g_i - g_j)$	0.091	

Table LXI

Analysis of variance, and G.C.A.'s for habit. Spaced plant treatment.

Source of variance	Sums of squares	Degrees of freedom	Mean square	F ratio	P<
Replications (R)	37.96	9	4.218	2.109	.05
Lines (L)	238.30	43	5.542	2.772	.01
Error	737.84	369	2.000	*	

Parent (i)	g_i	Rank
1	-0.03	6
2	-0.08	7
3	-0.17	8
4	0.23	2
5	0.01	4
6	-0.38	10
7	-0.26	9
8	0.40	1
9	0.22	3
10	-0.01	5
S.E. (g_i)	0.11	
S.E. $(g_i - g_j)$	0.16	

Table LXII

Regression of green weight (gms) on tiller number (per plant). November harvest. Spaced plant treatment. (See Fig. 7.)

Progeny*	Regression coefficient	95% Confidence limits	5% Least significant difference[+]	Equation of line (y = green weight) (x = tiller number)
1	0.56	± 0.19	│	y = 49 + 0.56x
10	0.41	± 0.18	│ │	y = 89 + 0.41x
5	0.39	± 0.18	│ │	y = 118 + 0.39x
7	0.36	± 0.09	│ │	y = 108 + 0.36x
9	0.34	± 0.15	│ │	y = 133 + 0.34x
3	0.33	± 0.12	│ │	y = 111 + 0.33x
4	0.31	± 0.21	│ │	y = 147 + 0.31x
6	0.26	± 0.21	│	y = 135 + 0.26x
2	0.21	± 0.17	│	y = 179 + 0.21x
8	0.19	± 0.22	│	y = 197 + 0.19x

*All the offspring of parent 1 are referred to as progeny 1, etc.

[+]Values opposite a common line are not significantly different at the 5% probability level.

Table LXIII

Correlation coefficients between green weight and tiller number.

November harvest. Spaced plant treatment.

Rrogeny	Correlation coefficient	S.E.	Significance of coefficient	5% Least significant difference
7	0.86	0.20	.001	│
1	0.77	0.21	.001	│ │
3	0.74	0.20	.001	│ │
9	0.73	0.22	.001	│ │ │
10	0.70	0.22	.001	│ │ │
5	0.68	0.21	.001	│ │ │
4	0.61	0.21	.01	│ │
6	0.55	0.21	.01	│ │
2	0.46	0.20	.05	│ │
8	0.34	0.21	NS	│

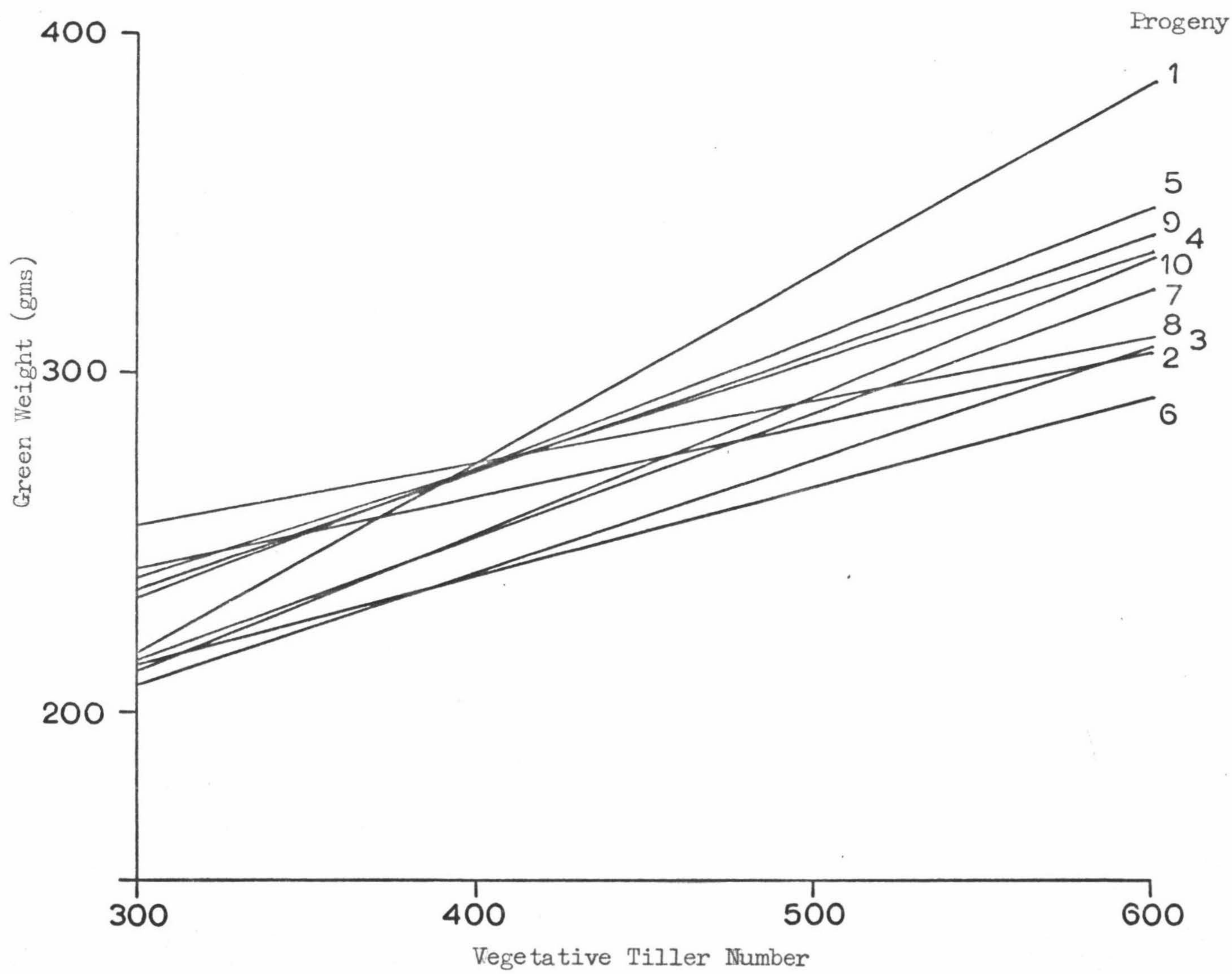


Fig. 7. Regression lines of green weight (gms) on tiller numbers in the spaced plant treatment for the November harvest.

Table LXIV

Regression of green weight (gms) on tiller number (per plant). November harvest. Sward treatment. (See Fig. 8.)

Progeny	Regression coefficient	95% Confidence limits	5% Least significant difference	Equation of line (y = green weight) (x = tiller number)
4	1.02	± 0.22	│	y = -15.4 + 1.02x
8	1.08	± 0.15	│	y = -5.3 + 1.08x
10	0.83	± 0.14	│ │	y = 2.8 + 0.83x
9	0.81	± 0.25	│ │ │	y = 0.1 + 0.81x
2	0.69	± 0.20	│ │	y = 6.3 + 0.69x
5	0.67	± 0.12	│ │	y = 15.4 + 0.67x
7	0.65	± 0.14	│ │	y = 6.3 + 0.65x
1	0.65	± 0.22	│ │	y = 8.3 + 0.65x
3	0.64	± 0.16	│ │	y = 12.4 + 0.64x
6	0.59	± 0.16	│	y = 11.0 + 0.59x

Table LXV

Correlation coefficients between green weight and tiller number. November harvest. Sward treatment.

Progeny	Correlation coefficient	S.E.	Significance of coefficient	5% Least significant difference
8	0.94	0.22	.001	│
10	0.94	0.20	.001	│ │
5	0.92	0.20	.001	│ │ │
7	0.89	0.21	.001	│ │ │
4	0.89	0.21	.001	│ │ │
3	0.86	0.21	.001	│ │ │
6	0.85	0.20	.001	│ │ │
9	0.84	0.21	.001	│ │ │
2	0.81	0.24	.001	│ │
1	0.79	0.22	.001	│

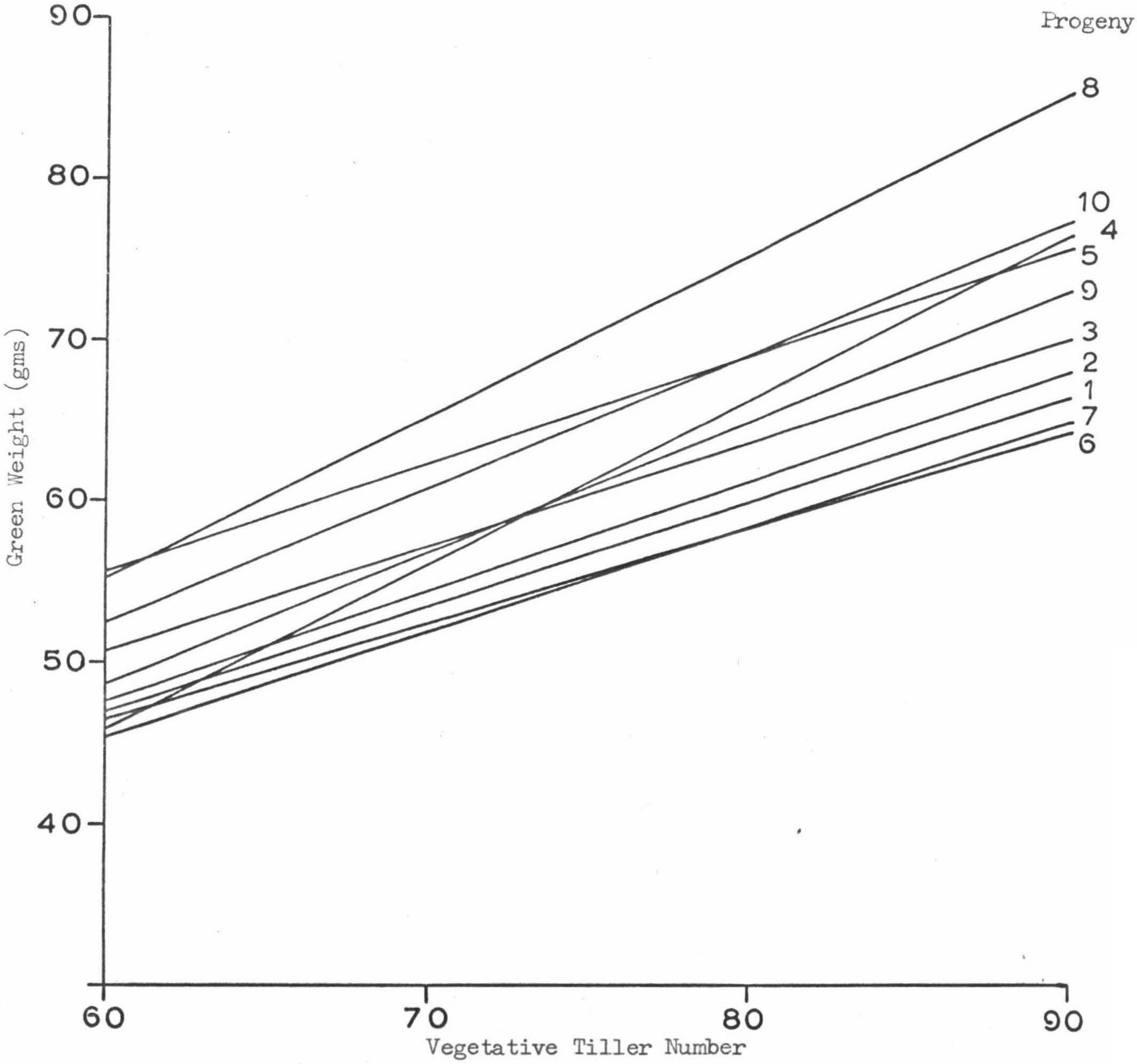


Fig. 8. Regression lines of green weight (gms) on tiller number in the sward treatment for the November harvest.

Table LXVI

Average tiller number and average green weight (gms) per plant, and average tiller weight (gms). Replications 3, 5 and 7 only. November harvest.

Progeny	Spaced plant treatment			Sward treatment		
	Plant wt. (gms)	Tiller number	Tiller wt. (gms)	Plant wt. (gms)	Tiller number	Tiller wt. (gms)
1	250	360	0.70	49	62	0.78
2	290	510	0.56	57	74	0.77
3	260	450	0.57	56	69	0.81
4	300	490	0.61	71	85	0.83
5	270	390	0.69	69	80	0.86
6	230	380	0.62	48	63	0.77
7	290	500	0.58	62	86	0.72
8	280	410	0.67	56	61	0.92
9	290	480	0.60	66	82	0.81
10	270	450	0.61	63	72	0.87

Table LXVII

Regression of green weight (gms) on fertile tiller number (per plant). Spaced plant treatment. January harvest. (See Fig. 9.)

Progeny	Regression coefficient	S.E.	5% Least significant difference	Equation of line (y = green weight) (x = tiller number)
3	1.24	0.14		$y = 118 + 1.24x$
5	1.19	0.13		$y = 193 + 1.19x$
4	1.18	0.15		$y = 189 + 1.18x$
9	1.16	0.17		$y = 184 + 1.16x$
10	1.08	0.17		$y = 266 + 1.08x$
2	1.03	0.15		$y = 206 + 1.03x$
7	0.99	0.16		$y = 190 + 0.99x$
1	0.84	0.16		$y = 230 + 0.84x$
8	0.83	0.16		$y = 321 + 0.83x$
6	0.79	0.14		$y = 220 + 0.79x$

Table LXVIII

Correlation coefficients between green weight and fertile tiller number. Spaced plant treatment. January harvest.

Progeny	Correlation coefficient	S.E.	5% L.S.D.
5	0.70	0.11	
3	0.70	0.11	
4	0.65	0.11	
9	0.62	0.11	
10	0.59	0.11	
2	0.59	0.11	
7	0.55	0.11	
6	0.54	0.11	
1	0.51	0.12	
8	0.48	0.11	

All coefficients are significant at the $P < .001$ level.

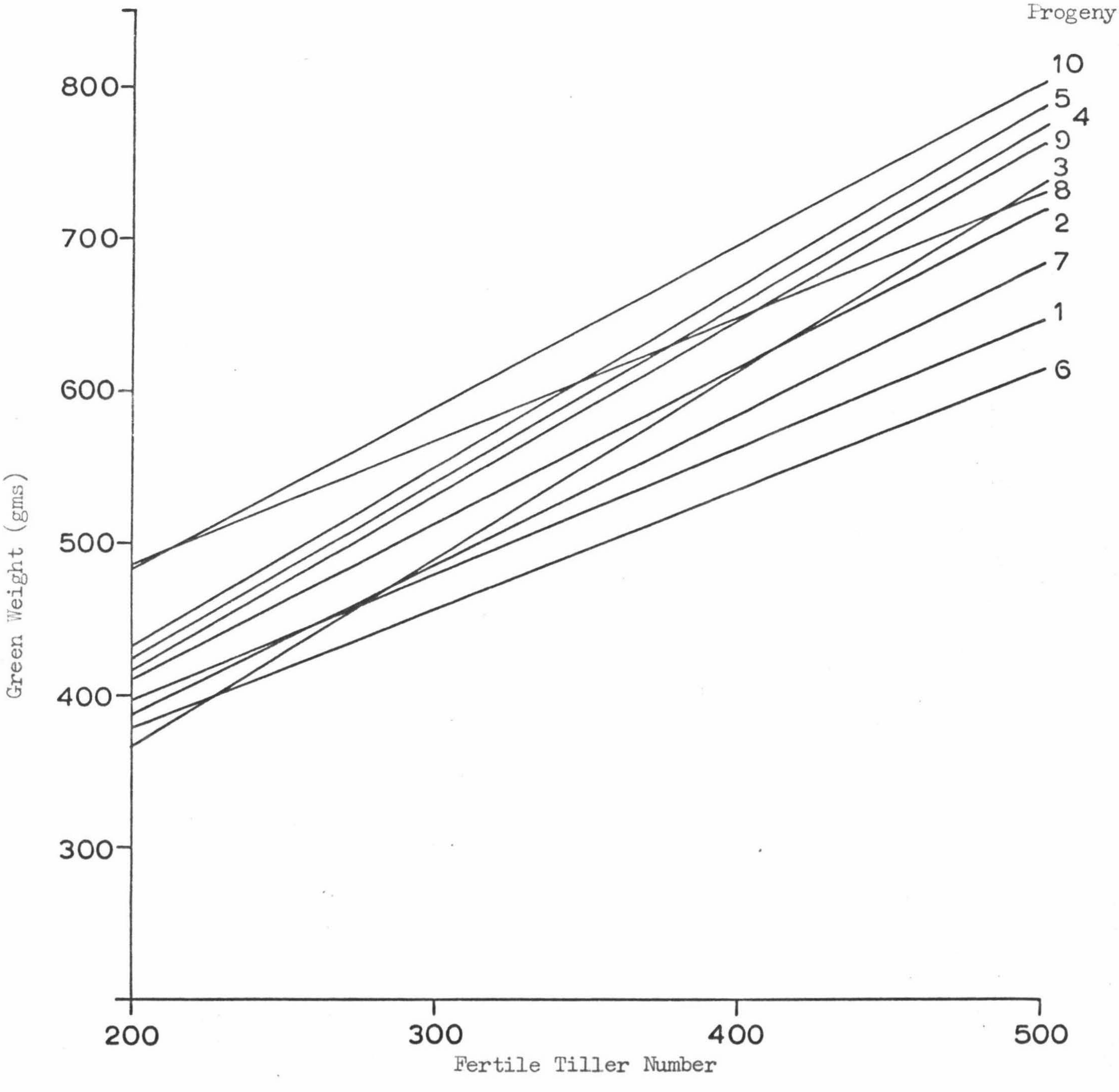


Fig. 9. Regression of green weight (gms) on fertile tiller number for the spaced plant treatment for the January harvest.

Table LXIX

Regression of green weight (gms) on fertile tiller number (per plant). Sward treatment. January harvest. (See Fig. 10.)

Progeny	Regression coefficient	S.E.	5% L.S.D.	Equation of line. (y = green weight) (x = tiller number)
10	1.77	0.07		y = -1.27 + 1.77x
9	1.71	0.09		y = -0.78 + 1.71x
3	1.67	0.06		y = -3.61 + 1.67x
5	1.65	0.08		y = -0.93 + 1.65x
2	1.61	0.06		y = -0.98 + 1.61x
8	1.57	0.10		y = 3.66 + 1.57x
4	1.54	0.07		y = 2.50 + 1.54x
7	1.52	0.04		y = -7.23 + 1.52x
1	1.19	0.07		y = 4.69 + 1.19x
6	1.16	0.06		y = 2.79 + 1.16x

Table LXX

Correlation coefficients between green weight and tiller number. Sward treatment. January harvest.

Progeny	Correlation coefficient	S.E.	5% L.S.D.
7	0.934	0.077	
10	0.905	0.081	
3	0.903	0.077	
2	0.896	0.076	
4	0.892	0.084	
9	0.862	0.087	
5	0.861	0.079	
6	0.846	0.087	
1	0.807	0.085	
8	0.779	0.079	

All correlations are significant at the $P < .001$ level.

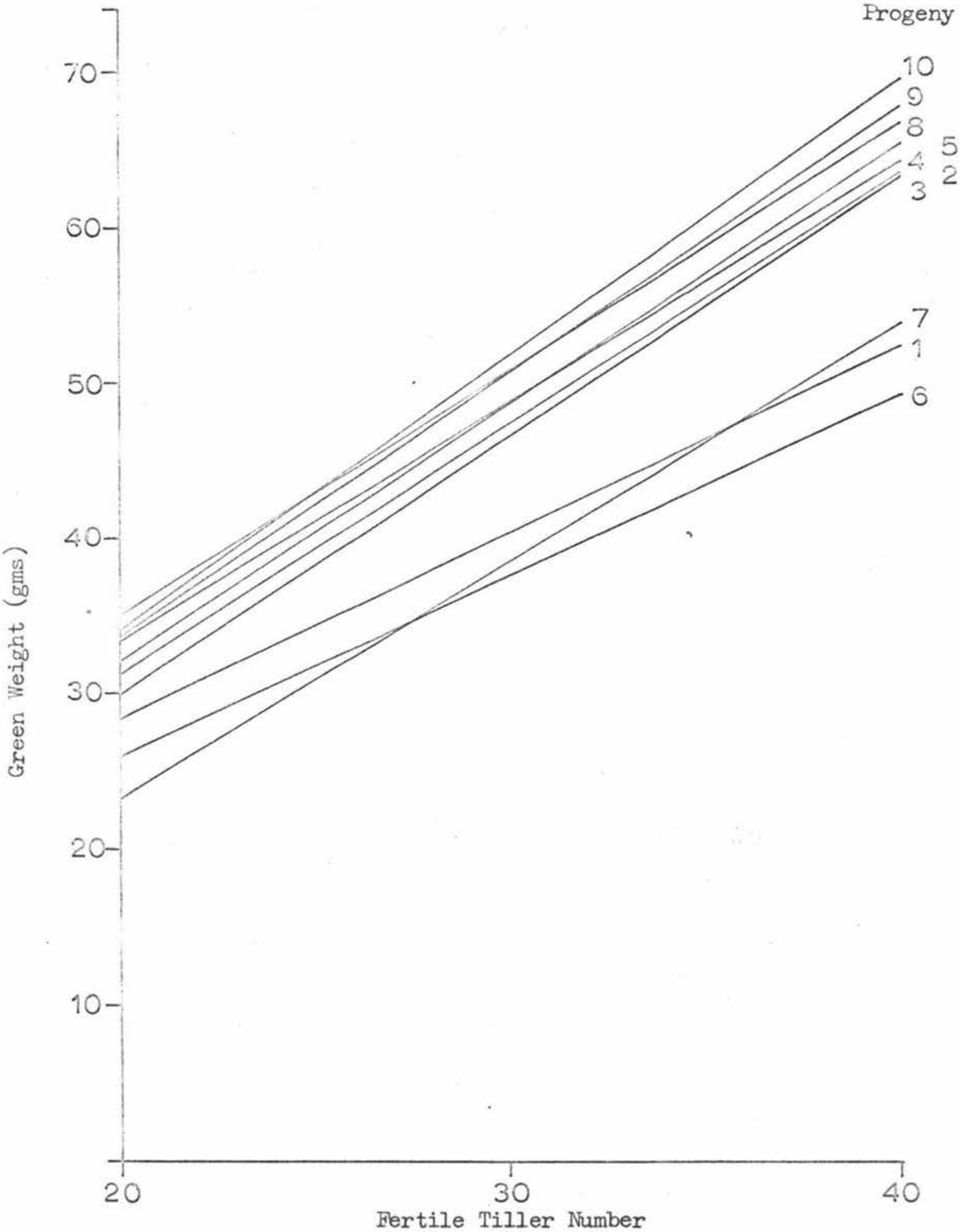


Fig. 10. Regression of green weight (gms) on fertile tiller number for the sward treatment for the January harvest.

Table LXXI

Fertile tiller numbers. January harvest.

Progeny	Spaced plant treatment	Sward treatment
1	410	23.3
2	370	26.0
3	370	26.7
4	410	29.1
5	330	25.7
6	390	23.9
7	460	31.1
8	290	21.7
9	390	36.6
10	360	25.3
S.E.	20	1.5

Table LXXII

Ratios of fertile tiller number (January) to vegetative tiller number (November).

Progeny	Spaced plant treatment	Sward treatment
1	1.14	0.37
2	0.73	0.35
3	0.82	0.39
4	0.84	0.34
5	0.85	0.32
6	1.03	0.38
7	0.92	0.36
8	0.71	0.36
9	0.81	0.45
10	0.80	0.35

Table LXXIII

Regressions of fertile tiller number on vegetative tiller number measured in November. Spaced plant treatment. (See Fig. 11.)

Progeny	Regression coefficient	95% confidence limits	Equation of line (y = fertile tillers) (x = vegetative tillers)
1	0.43	± 0.24	$y = 260 + 0.43x$
2	0.22	± 0.22	$y = 270 + 0.22x$
3	0.38	± 0.18	$y = 190 + 0.38x$
4	0.37	± 0.18	$y = 210 + 0.37x$
5	0.34	± 0.29	$y = 200 + 0.34x$
6	0.38	± 0.24	$y = 210 + 0.38x$
7	0.41	± 0.29	$y = 280 + 0.41x$
8	0.23	± 0.27	$y = 210 + 0.23x$
9	0.22	± 0.24	$y = 280 + 0.22x$
10	0.40	± 0.25	$y = 190 + 0.40x$

The coefficients are not significantly different at the 5% level.

Table LXXIV

Correlation coefficients between fertile tiller number and November vegetative tiller number. Spaced plant treatment.

Progeny	Correlation coefficient	S.E.	Significance of coefficient
1	0.59	0.21	.01
2	0.35	0.20	NS
3	0.65	0.20	.001
4	0.66	0.21	.001
5	0.44	0.21	.05
6	0.56	0.21	.01
7	0.50	0.20	.01
8	0.34	0.21	NS
9	0.38	0.22	NS
10	0.59	0.22	.01

The coefficients are not significantly different at the 5% level.

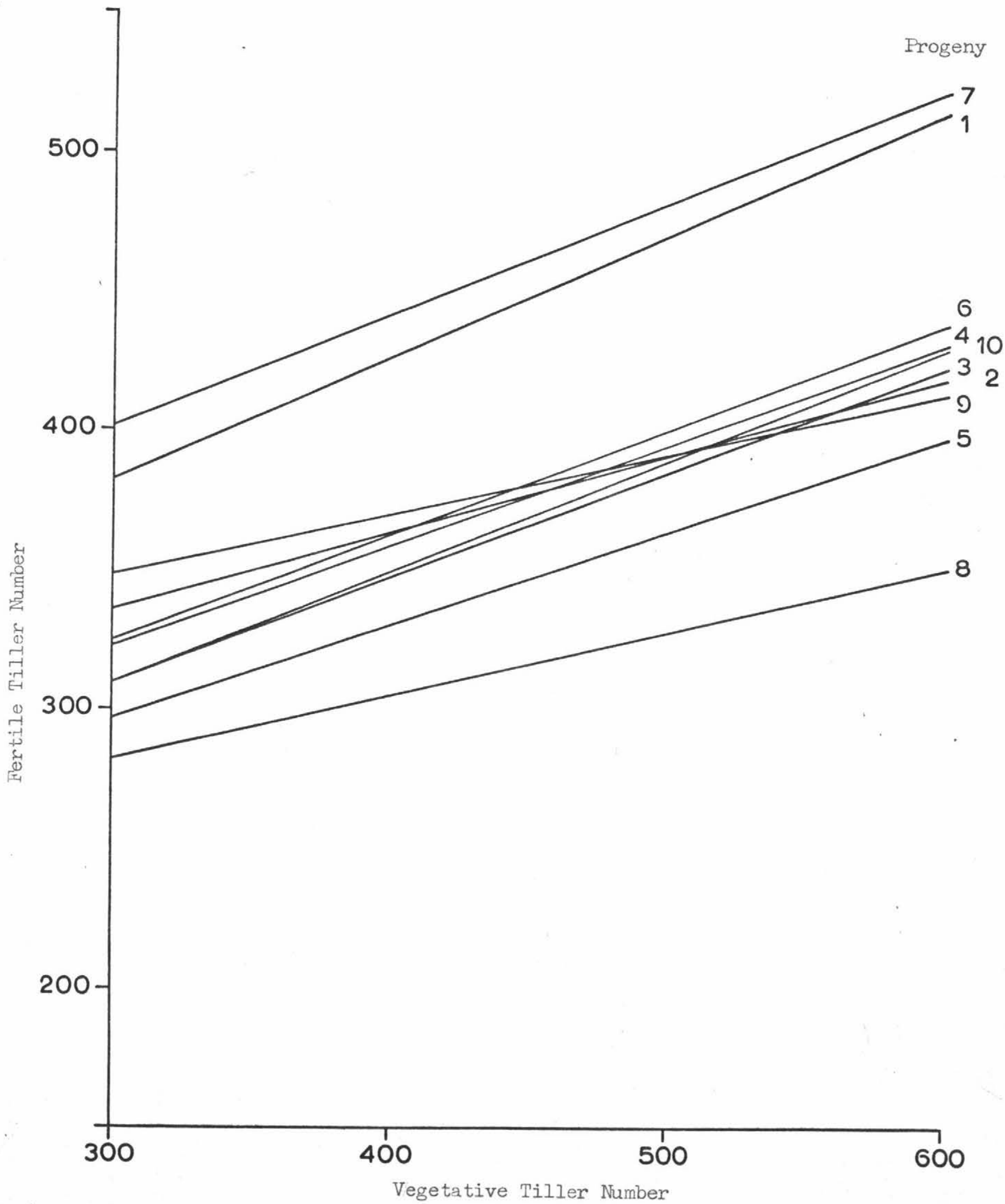


Fig. 11. Regressions of fertile tiller numbers on vegetative tiller numbers measured in November. Spaced plant treatment.

Table LXXV

Regressions of fertile tiller number on November vegetative tiller number. Sward treatment. (See Fig. 12.)

Progeny	Regression coefficient	95% Confidence limits	5% L.S.D.	Equation of line (y = fertile tillers) (x = vegetative tillers)
9	0.58	± 0.25		y = -14.5 + 0.58x
8	0.42	± 0.11		y = -2.5 + 0.42x
4	0.39	± 0.14		y = -1.0 + 0.39x
2	0.38	± 0.17		y = -3.7 + 0.38x
3	0.37	± 0.13		y = 3.0 + 0.37x
5	0.35	± 0.24		y = 0.9 + 0.35x
10	0.35	± 0.12		y = -1.7 + 0.35x
7	0.31	± 0.09		y = 4.0 + 0.31x
6	0.25	± 0.25		y = 13.1 + 0.25x
1	0.21	± 0.05		y = 10.4 + 0.21x

Table LXXVI

Correlation coefficients between fertile tiller number and November vegetative tiller number. Sward treatment.

Progeny	Correlation coefficient	S.E.	Significance of coefficient	5% L.S.D.
10	0.95	0.22	.001	
8	0.89	0.20	.001	
2	0.83	0.20	.001	
9	0.75	0.21	.001	
5	0.75	0.21	.001	
3	0.75	0.21	.001	
7	0.73	0.20	.001	
4	0.69	0.22	.001	
6	0.46	0.24	.05	
1	0.35	0.22	NS	

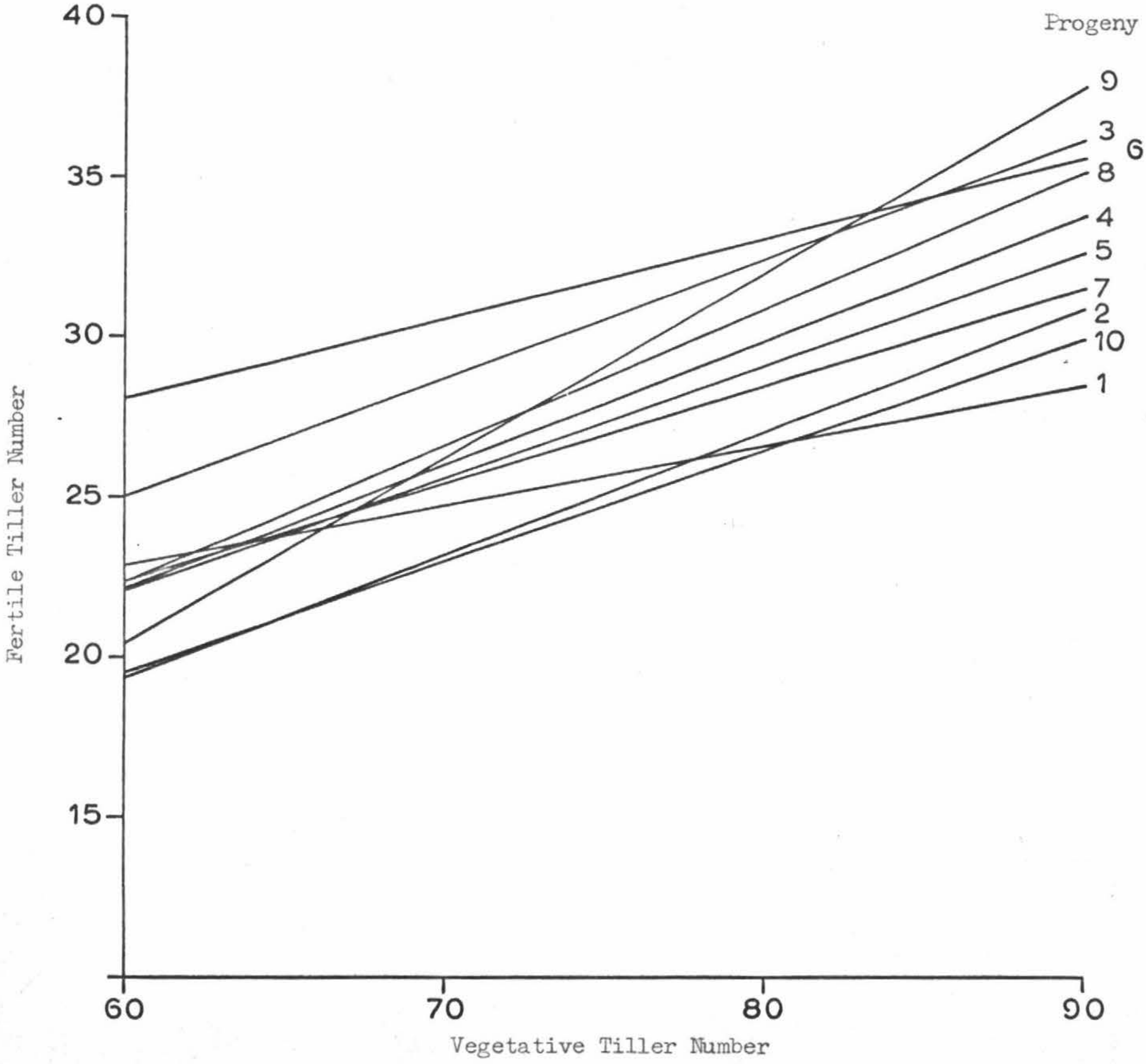


Fig. 12. Regressions of fertile tiller number on November vegetative tiller number. Sward treatment.

Table LXXVII

Regression coefficients of green weight (gms) on plant position in the sward treatment. January harvest. (See Fig. 13.)

x = 1 for rows 1 and 6
x = 2 for rows 2 and 5
x = 3 for rows 3 and 4

Progeny	Regression coefficient	S.E.	5% L.S.D.	Equation of line
9	-37.1	6.7		y = 136 - 37.1x
4	-26.4	4.6		y = 102 - 26.4x
3	-22.3	5.5		y = 90 - 22.3x
6	-20.2	3.6		y = 72 - 20.2x
7	-19.4	4.6		y = 79 - 19.4x
5	-19.2	4.3		y = 79 - 19.2x
2	-18.2	4.4		y = 79 - 18.2x
8	-17.8	4.9		y = 75 - 17.8x
1	-17.7	4.0		y = 70 - 17.7x
10	-16.4	4.6		y = 80 - 16.4x

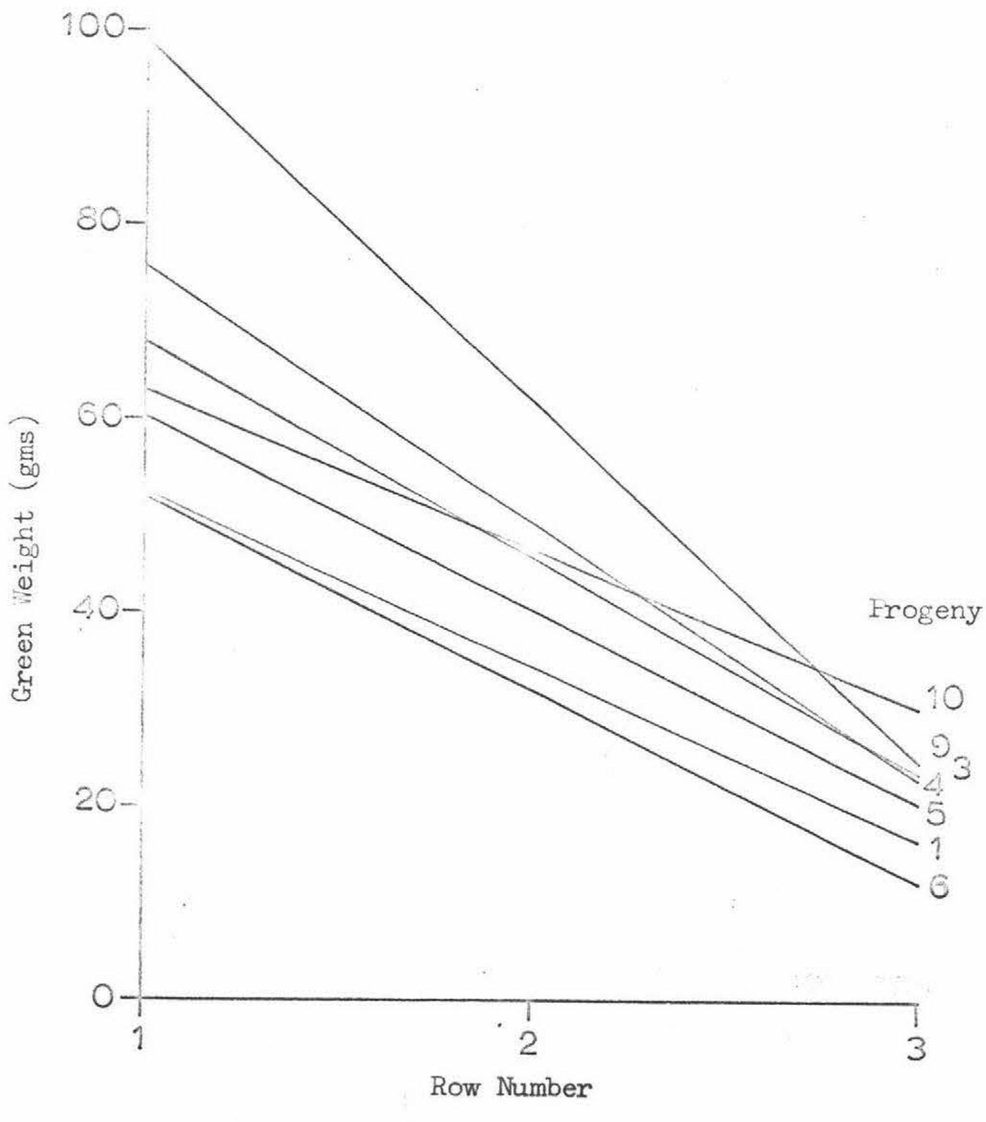


Fig. 13. Regression of green weight (gms) on plant position in the sward for the January harvest. Regression lines of progenies 2, 7 and 8 are not drawn for the sake of clarity. They are similar to that of 5.

Table LXXVIII

Regression of seed production (gms) on fertile tiller number (per plant). Spaced plant treatment. (See Fig. 14.)

Progeny	Regression coefficient	S.E.	5% L.S.D.	Equation of line (x = fertile tiller number) (y = seed weight)
3	0.093	0.010		y = -8.05 + 0.093x
10	0.085	0.011		y = 0.33 + 0.085x
5	0.082	0.010		y = 1.81 + 0.082x
8	0.061	0.007		y = 2.05 + 0.061x
1	0.055	0.011		y = 8.15 + 0.055x
9	0.053	0.011		y = 6.64 + 0.053x
2	0.052	0.009		y = 9.49 + 0.052x
6	0.052	0.009		y = 4.34 + 0.052x
7	0.047	0.013		y = 15.05 + 0.047x
4	0.046	0.012		y = 11.38 + 0.046x

Table LXXIX

Correlation coefficients between seed production and fertile tiller number. Spaced plant treatment.

Progeny	Correlation coefficient	S.E.	5% L.S.D.
3	0.71	0.11	
8	0.69	0.11	
5	0.67	0.11	
10	0.65	0.12	
6	0.56	0.11	
2	0.52	0.11	
9	0.50	0.12	
1	0.49	0.11	
4	0.41	0.11	
7	0.36	0.11	

All coefficients are significant at the 0.1% level

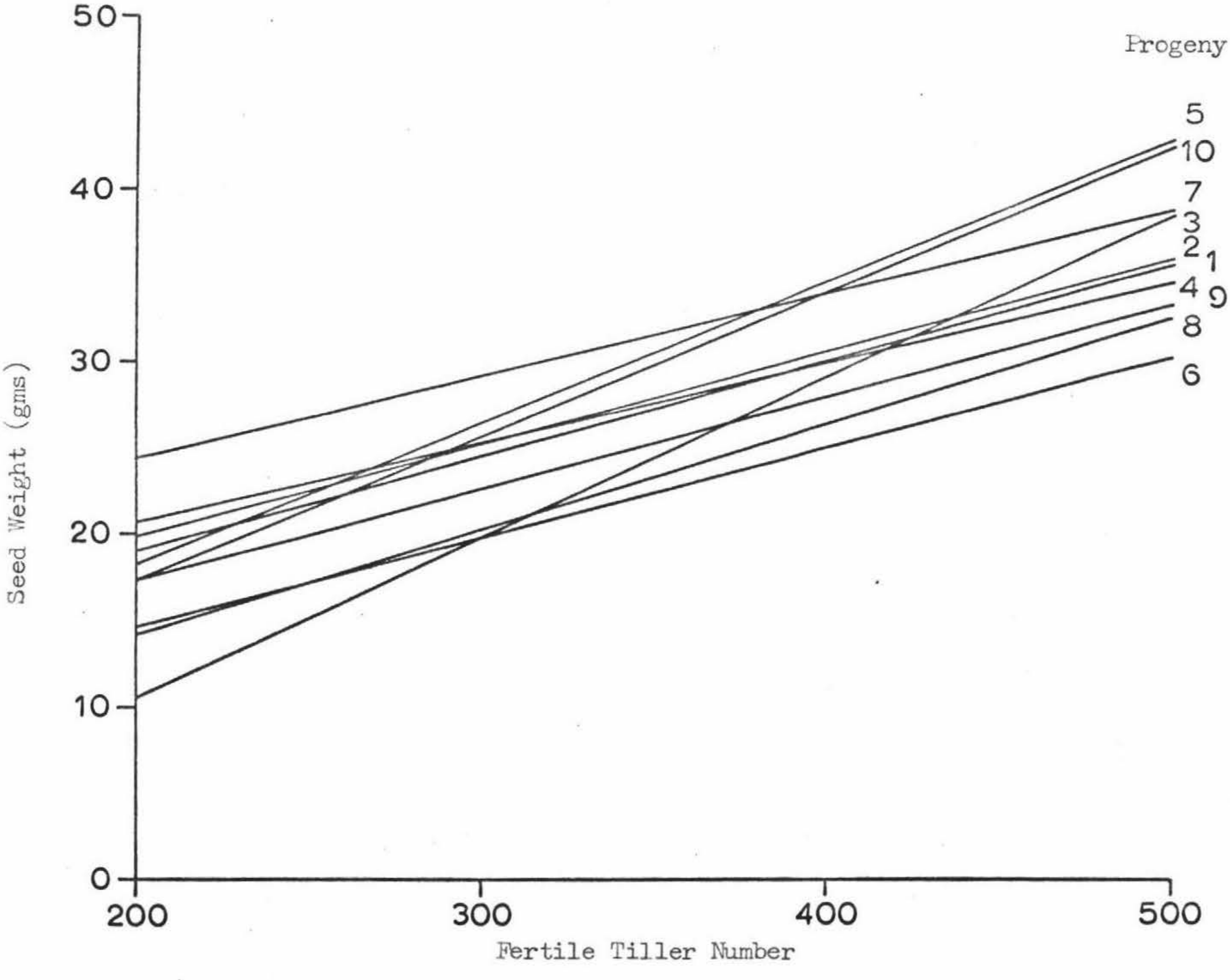


Fig. 14. Regression of seed weight (gms) on fertile tiller number for the spaced plant treatment.

Table LXXX

Regression of seed production (gms) on fertile tiller number (per plant). Sward treatment. (See Fig. 15.)

Progeny	Regression coefficient	S.E.	5% L.S.D.	Equation of line (x = fertile tiller number) (y = seed weight)
10	0.0862	0.0038		$y = 0.251 + 0.0862x$
3	0.0793	0.0024		$y = -0.277 + 0.0793x$
5	0.0781	0.0032		$y = -0.059 + 0.0781x$
2	0.0740	0.0040		$y = 0.021 + 0.0740x$
8	0.0712	0.0039		$y = 0.038 + 0.0712x$
7	0.0649	0.0034		$y = 0.022 + 0.0649x$
9	0.0636	0.0042		$y = 0.207 + 0.0636x$
4	0.0621	0.0042		$y = 0.185 + 0.0621x$
1	0.0595	0.0046		$y = 0.315 + 0.0595x$
6	0.0503	0.0038		$y = 0.266 + 0.0503x$

Table LXXXI

Correlation coefficients between seed production and fertile tiller number. Sward treatment.

Progeny	Correlation coefficient	S.E.	5% L.S.D.
3	0.93	0.08	
5	0.89	0.08	
10	0.88	0.08	
7	0.82	0.08	
8	0.82	0.08	
2	0.82	0.08	
9	0.79	0.09	
4	0.78	0.09	
6	0.77	0.09	
1	0.75	0.09	

All coefficients are significant at the 0.1% level.

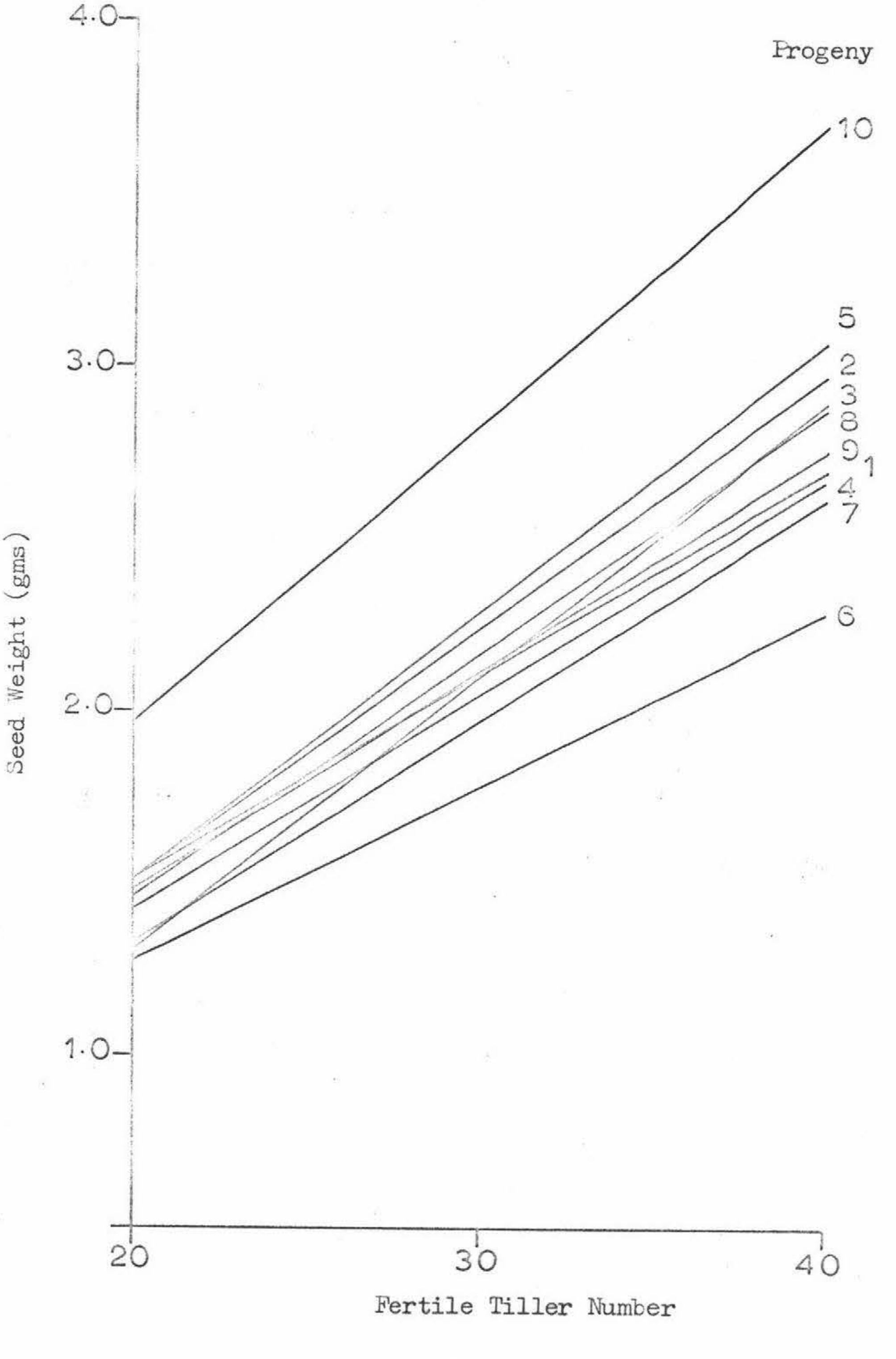


Fig. 15. Regression of seed weight (gms) on fertile tiller number for the sward treatment.

CHAPTER IV

DISCUSSION

General Appraisal

The data presented in the previous chapter show that for all characters analysed (green weight for three harvests, seed production and flowering time), there were interactions between the lines and treatments. These interactions, while slight in the September harvest, became more pronounced at later harvests.

Interactions also occurred for general combining ability (G.C.A.) in all analyses, showing that some parents produce offspring more responsive to decreased competition than others.

Interactions for green weight

September Harvest

From the first analysis of variance, Table VIII, it can be seen that line-by-treatment interaction is significant even in the early stages of growth. This interaction is, however, scarcely within the 5% level of significance, and would not be significant in an experiment with substantially fewer degrees of freedom. These results compare with those of Kelly (1958), who showed that a relationship between sward and spaced plant performance existed only during the early spring; the inference is that, if present, the interaction between lines and spacings was not then significant.

Knight (1960) showed that the correlation between widely and closely spaced plants deteriorated as the swards aged. The latter harvests in the present experiment show that the interactions become more pronounced, thus substantiating the above-mentioned work.

The analysis of the combining effects of the parents (Table XI) show substantial interaction for the G.C.A.'s. The comparison of the rankings for the G.C.A.'s (Table XIV) show that parents 2, 4, 8 and 10 differ most in rank between the spaced plant and sward assessment. Parents 9, 7, 5 and 6 show little change in rank between treatments. Table VII shows that of the lines which contribute towards the interaction effects, lines 1, 3, 10, 12, 14, 25 and 37 differ most in ranking between treatments. It can be seen from Table II that parent 2 contributes to lines 1, 10, 12 and 14. The offspring of the other parents show less change in rankings.

Table XIV presents the variances for the specific combining abilities, (S.C.A.) for each parent. These show that in the spaced plant treatment, parents 9 and 4, both with high G.C.A.'s have widely differing variances for their respective S.C.A.'s. Parent 9 can be seen to obtain its high rank for G.C.A. from uniformly highly productive crosses, while parent 4 tends to have less uniform offspring. In the sward treatment parent 9, still with a high G.C.A., has a low S.C.A. variance. Parent 4, however, with a reduced relative G.C.A. has a greatly reduced rank for S.C.A. variance. Parent 7, on the other hand, which ranks third in the spaced treatment, where its S.C.A. variance is high, ranks second in the sward treatment, still with a high S.C.A. variance. Obviously, no general conclusions can be drawn.

The components of the combining ability mean squares (Tables XII and XIII) show that in spite of the high levels of interactions the differences in G.C.A., as estimated by $\frac{1}{9}\sum g^2$, account for 17% of the variation; differences in S.C.A., estimated by $\frac{1}{35}\sum s^2$, account for 54 to 55% of the variation; and uncontrollable variation accounts for 28 to 29%, regardless of the treatment.

November Harvest

The November harvest analysis (Table XIX) shows that the interaction of lines with treatments has become highly significant. The comparisons of G.C.A.'s (Table XXV) show that the parental lines most affected by competition are not necessarily the same as for the previous harvest (Table VIV). The G.C.A.'s for parent 7 for each treatment for the November harvest are consistent with its previous G.C.A.'s, while parent 4 shows a similar response to reduced competition for both harvests. Parent 2, however, previously showing a relatively better G.C.A. in the sward than the spaced plant treatment, now shows no such interaction as the G.C.A.'s rank sixth in each treatment. Parents 9 and 5, previously uniformly good in both treatments, now shows reduced response to reduced competition. The lines showing most change in ranking between treatments for mean green weight are 3, 12, 23 and 41 (Table XVIII). Parent 2 contributed less towards these lines than the lines possessing extreme interaction in the previous harvest, thus substantiating the point made about parent 2 above, i.e., that its offspring are no longer counted amongst those with extreme interactions.

The S.C.A. variances of parents 2, 4, 5, 6, 7 and 9 show for the November harvest a similar pattern between treatments to the September harvest. It appears that changes in G.C.A. ranking cannot be readily attributed to changes in the variability of the offspring.

The components of the combining ability mean squares (Table XXIII and XXV) show that the variation accounted for by G.C.A. differences, S.C.A. differences, and uncontrollable variation have changed from the first harvest. The more significant interaction may account for the slight reduction in agreement between the partitioning of variation in the swards and spaced plant treatments. The swards appear to show more variation due to S.C.A. differences and uncontrollable sources. Both treatments, however, show that G.C.A. differences account for more of the variation than in the previous harvest. This is reflected in the higher (although still low) estimates of heritability (Table XXVIII).

January Harvest

The analysis of the January harvest green weight (Table XXX) shows that the interactions of lines with treatments have increased in significance still further. An increased F-ratio for the G.C.A. interaction is shown in Table XXXIII. The table of G.C.A.'s (Table XXXVI) shows that parents 9 and 10 have high G.C.A.'s in both treatments, while parent 3, with a relatively low spaced plant G.C.A., has a high G.C.A. in the sward assessment. Parent 4, however, which ranked first for the spaced plant treatment G.C.A., loses this superiority in the sward. Similar reduced relative performances for G.C.A. occur with parents 1 and 7.

The high G.C.A. possessed by parent 9 has been a consistent feature throughout all sward harvests. Its performance in the spaced planted treatment is less uniform, being ranked first for the September harvest (Table XIV), fifth for the November harvest (Table XXV) and third for the January harvest (Table XXXVI).

The performance of parent 10, the half-sib of 9, is interesting in that the G.C.A.'s, initially significantly different in the first harvest, become ranked adjacently in the final harvest, for both treatments, even though the G.C.A. for parent 9 is significantly superior to all the others in the final sward assessment.

Parent 4, consistently high in G.C.A. in the spaced plant treatment, has only an average G.C.A. in the swards. The spaced plant treatment G.C.A.'s of parent 3 diverge from its half-sib, parent 4, in the latter harvests, while the opposite phenomenon occurs in the sward treatment.

No definite pattern appears in the S.C.A. variances. Parent 4 has a relatively lower S.C.A. variance in the final spaced plant harvest than the first, while it stays relatively low in the sward harvest. Parent 9 has a higher S.C.A. variance in the January spaced plant harvest, while the sward S.C.A. variance stays relatively low.

A change has also occurred in the components of mean squares for the combining abilities (Tables XXXIV and XXXV). Differences in S.C.A.'s as estimated by $\frac{1}{35}\sum s^2$ account for a far larger proportion of the variation in the spaced plant than in the sward treatments. The differences in G.C.A.'s account for more of the variation in the swards, and the uncontrollable variation is relatively higher in the swards. This shows that the spaced plant method of assessment that was used in the breeding programme for "Ariki" has probably reduced the additive genetic variance for that environment (i.e. spaced plants). As might be expected, the additive genetic variation is higher in the environment where less selection was employed (e.g. in the simulated sward environment).

The heritability estimates, however, are still similar between treatments as the higher G.C.A. variances in the swards are effectively countered by the increased uncontrollable variance.

Seed Production

The analysis of variance for seed production (Table XLI) shows highly significant line-by-treatment interaction. Those lines which change in rank most between treatments can be seen from Table XL to be 3, 6, 7, 8, 14, 16, 23, 27 and 29. From Table XI it can be seen that parents 7 and 9 contribute most towards these lines, while parents 1 and 4 contribute less. The change in rank of the G.C.A.'s for seed weight reflects this interaction. Parent 1, ranked third for the spaced plant treatment G.C.A., is ranked ninth in the swards, while parent 9, ranked seventh in the spaced plant treatment, is ranked first in the swards. The significance of the G.C.A. interaction with treatment is very high (Table XLIV).

It will be noticed, in comparing the components of the mean squares (Tables XLV and XLVI), that the proportion of the total variance due to G.C.A. differences is far lower in the sward treatment than the spaced plant treatment. The proportion due to S.C.A . differences is similar, while the error variance is higher for the sward treatment than the spaced. This is a reflection of the edge effect in the swards, which could not be entirely removed by using weighted data. An interesting feature is that the ratio of $\frac{1}{9}\sum g^2$ to $\frac{1}{35}\sum s^2$ is far lower in the sward treatment than the spaced plant treatment. This along with the higher error variances in the sward, results in a lower heritability estimate for seed yield in the sward than in the spaced plant treatment (Table L).

Seed production, while not ignored in the Ariki breeding programme, was not a character under selection. Consequently, in the population, seed yield would be expected to show more additive genetic variance than a highly selected character such as yield of green matter. This appears to be the case, as the spaced plant heritabilities for green weight are lower than for seed yield. In the sward treatments, however, the argument fails; there has been no selection for sward green yield or seed yield, but the heritability estimates are all uniformly low and less than the estimates for the spaced plant treatment. This can be ascribed to the increased error variances in all cases and reflects the high variability of plants of a line under competition. Alternatively, differences in heritability estimates could be ascribed to differences in ratios between additive genetic and total variance. It is possible for a lower additive genetic variance to be associated with a higher estimate of heritability, if the total variance alters sufficiently.

Some relationship between seed production and time of flowering may be expected, but here the rankings for G.C.A. for flowering time (Table LVIII) do not coincide with the rankings for G.C.A. for seed production (Table XLVII). While parent 6 ranks ninth for both seed production and flowering time G.C.A. in the spaced plant treatment, parent 7, first for seed production, is fifth for flowering time G.C.A. A closer look at the tables shows that the parents ranked between 1 and 5 for seed production G.C.A. are also ranked between 1 and 5 for time of flowering G.C.A., suggesting that the later flowering lines produce more harvested seed. Parent 2, however, ranked first for G.C.A. time of flowering (i.e. last to start flowering), is ranked fifth for seed production G.C.A., while parent 5, ranked last for time of flowering G.C.A., is ranked sixth for seed production. It can be seen that other parents, i.e., 7 and 8, also show similar but less extreme trends.

In the sward treatment, the rankings for G.C.A.'s for seed production are in approximately the same order for flowering time, with the notable exceptions of parent 3, 8 and 9. No definite conclusion can be drawn about the relationship between flowering time and seed yield.

As the first two seed increase generations of Ariki were sown as spaced plants it could be suggested that the offspring of parent 7 (i.e. progeny 7) would be inclined to be selected as the offspring of this parent have the highest seed yield in the spaced plant treatments. These progenies have quite satisfactory autumn and spring sward growth (Tables XIV and XXV), but low summer growth (Table XXXVI). The plant type (assessed as a spaced plant) is inclined to possess higher aftermath heading (Table LIX), narrower leaves (Table LX), and a more prostrate growth habit (Table LXI) than the average.

The subsequent seed increase generations of Ariki, however, were sown as drilled swards. If the results of the simulated swards in this experiment are indicative of what happens in a drilled sward then, because of its higher seed production, the progeny of parent 9 would tend to be selected. Parent 9 is associated with high sward production (Tables XIV, XXV and XXXVI), while the spaced plant type has relatively lower aftermath heading (Table LIX), wider leaves (Table LX), and a rather more erect habit (Table LXI) than the average. This parent is also associated with earlier flowering time in the sward, although the flowering time assessed on spaced plants is little different from that of progeny 7.

It would be imprudent, however, to generalise as the simulated sward used in this experiment cannot be closely associated with a drilled sward, let along a sward planted elsewhere.

Green Yield and Tiller Number

The relationship between tiller number and green yield are shown in Tables LXII to LXX, and Figs. 7 to 10. These indicate that any attempt to measure green weight production from tiller number, with the purpose of selecting high yielding genotypes, is imprudent.

The November Harvest

The relationships between vegetative tiller number, tiller weight, and plant weight for the November harvest for three replications are given in Table LXII, LXIII, LXIV, LXV and LXVI. It will be noticed that although there are changes in rank, the deviations from the mean for green yield for the progeny of each parent are largely similar to the G.C.A.'s for those parents (Table XXV). The higher tiller weights for the swards appear to be anomalous. Lazenby & Rogers (1965a) found in Lolium perenne spaced plant vegetative tiller dry weights to be higher than sward vegetative tiller weights except during the summer and at the higher nitrogen levels. The effect was more pronounced in the second year. Here, the heavier sward tillers may be a reflection of the technique used for counting the tillers. The graphs for the regression of plant weight on tiller number, however, show that the plant weights decrease by a smaller proportion than the tiller numbers, which indicates that at lower tiller numbers, plants have heavier tillers. While this may be a reflection of the statistical methods used, the regression equations of tiller number on plant weight show that only for one progeny in each treatment is the percentage increase in tiller number greater than the percentage increase in plant weight over the range of average plant weights. As dry weight percentages are slightly higher in the swards, differences in dry weight percentages cannot be the cause of the heavier sward tillers.

Table LXVI shows that progenies with high tiller numbers in the spaced plant treatment tend to have higher green weight in the swards, with the exception of 2 and 5. While progenies appear to retain similar rankings for tiller weight between treatments, there appears to be little correlation between sward production and tiller weight.

Fig. 7 shows that due to the different regression coefficients for progenies 1 and 8, the former will have a higher plant weight than the latter for a tiller number of 500 to 600 while the reverse occurs for tiller numbers below 400. At even lower numbers, i.e. in the sward (Fig 8), 8 is still superior to 1, although the former now has its plant weight relatively more affected by tiller number than previously. The comparisons of green weight and tiller number show that the ranking for tiller number does not closely agree with ranking for green weight in the spaced plant treatment although in the swards the agreement is far better. This is reflected in the higher correlation coefficients in Table LXV compared with Table LXIII.

The January Harvest

The relationships between fertile tiller number and green weight for the January harvest are given in Tables LXVII and LXVIII, and in Figs. 9 and 10. As the whole ten replications were used, the standard errors of the coefficients are correspondingly lower than for the previous harvest. Also in the previous harvest there were very few fertile tillers, and vegetative tillers constituted virtually all the tillers in the plants. Here, however, fertile and vegetative tillers are both significant components of the plant weight, and if only one component, in this case fertile tillers, is measured the accuracy with which green weight can be estimated from the components is reduced. The increase in the number of replications, however, offsets this and the range of correlation coefficients is similar to that of the previous harvest. As the fertile tillers themselves were not weighed separately from the remainder of the plant material, no tiller weights are given.

A comparison of the spaced plant treatment results (Table LXII with

Table LXVII) reveals that the green weights of the progenies 8 and 6 are still relatively little affected by change in tiller number, while the green weights for progeny 5 still shows a considerable dependence on tiller number. Of the other progenies, 1 and 10 appear to be relatively less dependent on fertile tiller number than on vegetative tiller number, while 2 and 4 show the reverse effect. The progenies with low regression coefficients, 1, 6 and 8 also have low G.C.A.'s for green weight (Table XXXVI), which suggests a relationship were it not for progeny 3 with the highest regression coefficient, but with a G.C.A. equally as low. The regression coefficient of 3, however, can be seen not to be significantly different from that of 8. On the other hand, of the parents with low G.C.A.'s as spaced plants (Table XXXVI), 3 along shows a relatively higher G.C.A. in the sward treatment. This effect is not retained by those progenies possessing lower regression coefficients.

In the swards (Fig. 10; Table LXIX) it can be seen that the trend shown by progeny 8 is not retained at the lower tiller numbers. The graph shows three basic groups; progenies 1 and 6 with low regression coefficients, progeny 7 with a higher regression coefficient, and the remainder with not only higher regression coefficients but also having constantly higher green weights for a given tiller number.

The comparison of Table XXXVI with Table LXXI shows that progeny 7, with a high rank for fertile tiller number, has a relatively lower rank for G.C.A. for green weight. This is reflected in Figs. 9 and 10.

The relationships between green weight and tiller number are all fairly high (Table LXX) and show that apart from progeny 7, the ranks for tiller numbers agree closely with the rank for green weight G.C.A.

The performance by progeny 7 in the sward treatment appears to be highly anomalous. While it has a very high correlation coefficient between tiller number and green weight, its high tiller number is not reflected in high green weight G.C.A. The correlation coefficient is, however, a measure of correlation, not prediction, and the relatively low regression coefficient gives a more true indication. The low standard error associated with the regression coefficient is reflected in the high correlation coefficient, while progeny B, with a higher regression coefficient, but a larger standard error, has the lowest correlation coefficient.

This shows the danger associated with correlation coefficients. Although the general trend agrees, the performance of progeny 7 suggests that tiller numbers cannot be considered a reliable guide to green weight production.

Lazenby and Rogers (1964a) also found that while tiller number was a reliable index of yield per plant within varieties, it was a less reliable index of yield between varieties.

Vegetative and Fertile Tiller Numbers

Tables LXXII to LXXV, Figs. 11 and 12 show the relationship between the fertile tiller number and the vegetative tiller number. The former was measured at the January harvest, while the latter was measured at the previous November harvest. These show that in the spaced plant treatment, progenies 1 and 7 produce more fertile tillers than progenies 5 or 6 for a given number of vegetative tillers. It also shows that progeny 9 gives a relatively stable number of fertile tillers regardless of vegetative tiller number. The extrapolation of the graphs in Fig. 11 to the vegetative tiller numbers experienced in the sward suggests that progeny 9 might then have a greater proportion of fertile tillers arising from the vegetative tillers than the other progenies. Fig. 12 shows that this may be true. However, progeny 9 now shows that its fertile tiller number is highly dependent on vegetative tiller number while progeny 1 now shows that its fertile tiller number is relatively independent of vegetative tiller number.

There appears to be no clear relationship between the ratio of fertile to vegetative tillers and green matter production (c.f. Table LXXII with

XXXVI). While the spaced planted progenies with the highest ratios, i.e. 1, 6 and 7, show a reduced relative performance for green weight in the swards, progenies 2 and 8, with low ratios do not support the corollary that these should therefore show an increase in relative sward performance.

A further aspect of competition presented in Table LXXVII and Fig. 13, which show the effect on green weight due to plant position in the swards. Plants towards the edge of the sward have higher green weights than those placed towards the centre. This indicates that competition in the centre is higher than competition at the edges. Future simulated sward experiments should have more rows or border plants than the two used here.

Here, while progeny 9 shows a greater relative reduction in production due to increased competition, its initial superiority at lower levels of competition is retained at higher levels of competition and becomes second only to the related progeny 10 which, incidentally, is the least affected by increased competition. There does not appear to be a clear relationship between the response to increased competition within the sward and the increased competition between the main spacing treatments. Table XXXVI shows that while progeny 4 is ranked higher in the spaced plant treatment than 10, progeny 3 is not.

The graphs of progenies 1 and 6 show that while their relative reduction in green weight for increased competition is less than that of 9, their inferiority at the lower levels of competition is not lost at the higher levels. While this graph does suggest that progeny 9 may become less competitive at much higher levels of competition, it would be unwise to extrapolate.

A comparison of Tables XIV, XXV and XXXVI, which list the green weight G.C.A.'s for the three harvests, reveals that progeny 10 gradually improves its ranking in the swards. The difference in mean green weight between treatments increases with later harvests (Tables VII, XVIII and XXIX), indicating increasing competition in the swards relative to the spaced plantings; the increase in the

F ratio for the line-by-treatment interaction (Tables VIII, XIX and XXX) indicates that this is becoming more pronounced. The relatively improved performance of progeny 10 with increased competition at later harvests is in line with its relatively improved performance with increased competition with plant position in the sward at the last harvest. The other progenies do not appear to show quite the same clear relationship.

The relationship progeny 10 shows in Fig. 13 is for the final harvest only, and may not necessarily be the same relationship existing at any other time. The above-mentioned observation may be coincidental.

Seed production and fertile tiller number

The relationship between fertile tiller number and seed production is given in Tables LXXVIII to LXXXI and Figs. 14 and 15.

In both treatments progeny 5 and 10 have generally a higher seed production for a given tiller number than the rest. Seed production of progeny 3 is more dependent on tiller number.

A comparison of the G.C.A.'s (Table XLVII) with tiller numbers (Table LXXI) show that the rankings for each are roughly the same order, the notable exceptions being progenies 5, 6 and 10. Progenies 5 and 10, both with fewer tillers than 6, produced more seed for the same number of tillers, a superiority that enables them to out-perform 6 for seed production.

In the swards, progeny 10 again shows a high seed production per tiller - again giving it a high seed production in spite of a lower tiller number. Progenies 4, 6 and 7, however, show that their relatively better rank for tiller number than seed yield is a reflection of their poorer seed production per tiller as shown in Fig. 15.

There does not appear to be any definite relationship between treatments for seed production per tiller. Tables LXXVII and LXXX indicate a tendency for those progenies with high regression coefficients in one treatment to have high regression coefficients in the other treatment.

Characteristics of competitive ability

Rhodes (1968) suggested that a decline in competitive ability is associated with the onset of floral initiation. In this experiment, those progenies commencing flowering earliest would be those commencing floral initiation earliest, and therefore, other things being equal, should be sooner and therefore more affected by competition. Rhode's conclusions, however, were based on Phalaris coerulescens, which has a higher proportion of fertile tillers than Lolium perenne, and may not therefore be applicable to other species.

Early flowering progenies differ between treatments (Table LVIII), progenies 1, 4, 5 and 8 showing presence of interaction. However, progeny 3, with early flowering, performs relativelely better in the sward than the spaced plant treatment for green weight (Table XXXVI) as well as seed production (Table XLVII). Progeny 9, being early flowering in the swards, is superior to all other progenies for green weight (Table XXXVI) while progeny 10, a late flowering progeny, has a high green weight production which is, however, significantly less than that of 9.

Alternatively, it could be suggested that the progenies producing relatively more fertile tillers for a given number of vegetative tillers would be less aggressive. Even disregarding progeny 9, which shows the highest ratio of fertile to vegetative tillers (Table LXXII), the other progenies do not show a tendency for higher ratios to be associated with lowered competitive ability. Were the vegetative tiller counted for the January harvest, a different situation may have appeared. Progeny 3, which shows improved competitive ability in the swards (Table XXXVI), has a low fertile tiller number (Table LXXI). Progenies 4 and 7, both of which show lower competitive ability, have high fertile tiller numbers. Progeny 9, however, does not adhear to this pattern.

Rate of tiller production has been cited as the characteristic that enables Lolium perenne to compete strongly against Festuca pratensis (Milthorpe, 1961). Rhodes (1968) suggests that rate of tillering is a character associated with, rather than a determinant of competitive ability.

While production of green matter is highly correlated with tiller number, it is difficult to determine if the increased yield of the progenies with the higher tiller numbers is due to that alone, or due to the reduced yield of the lower tillering progenies that are less able to compete. From Table XXV it can be seen that progenies 4 and 5 are affected in opposing directions by increased competition. Progeny 4 has a higher tiller number than 5 in both the spaced plant and sward treatments, although the difference is not significant in the latter. Progeny 8 has a lower competitive ability compared with 9 and 10, and this is reflected in its lower sward tiller number. A comparison of monoculture with mixed swards of the type reported by Gardner & Hunt (1963) would not be easy here, unless the parents could be crossed to some neutral tester parents.

Donald (1963) suggests that the superior production of coastal Bermuda grass compared with the common variety is a reflection of the former variety having a more erect habit and more widely spaced leaves which allow a better distribution and utilization of light. In this experiment, progenies 4, 8 and 9 have an erect habit. While the latter two progenies show an improved performance in the sward compared with the spaced plant treatment, the erect habit possessed by 4 is insufficient to enable it to retain a high sward performance.

CHAPTER V

Conclusions.

Genetic variation.

This experiment has shown that considerable genetic variation exists for all characters examined, i.e., green matter production for three harvests, seed production, flowering time, growth habit, leaf width and after-math heading. Characters associated with yield, i.e., tiller number and tiller weight, also show genetic variation.

Differences in G.C.A.'s account for 17 - 27% (in the spaced plant treatment) and 17 - 36% (in the sward treatment) of the total variance for green matter production, while differences in S.C.A.'s account for 41 - 55% and 19 - 55% for the spaced plant and sward treatments respectively. While it is not possible to relate additive genetic variance and non-additive genetic variance directly to these values, they do show that even though some additive genetic variation remains to be fixed, the high levels of non-additive genetic variance would hamper selection experiments, especially in the earlier stages of growth. The low heritabilities estimated result partially from this fact.

While the non-additive genetic variance is classed as S.C.A. variance, this, and the error variance, could be partially attributable to maternal effects. If in each of the treatment blocks, the two plants of each cross had different maternal parents, maternal effects would be balanced out in the general analyses, and would largely contribute to error in the treatment analyses. However, in this experiment no attempt was made to balance maternal effects, nor, in a number of instances, would it have been possible.

The experiments reported by Beddows et al (1962), Haywood & Breese (1966, 1968), Haywood (1967), and Thomas (1967, 1969a, 1969b) all showed that ryegrass possesses considerable maternal effects which are not necessarily confined to seedling characters.

The tendency for the variance due to S.C.A. differences to decline in the sward treatments may be ascribable to reduced maternal effects. Alternatively, the reduced proportion of the genetic variance that is due to G.C.A. differences in the spaced plant treatment compared to the sward treatment , may be a reflection that "Ariki" was bred using spaced plant assessments, and that in this environment less additive genetic variance remains.

Interactions.

This experiment has successfully shown that for green matter production, seed yield and flowering time, genotype-by-environment interactions occurred with a sufficiently high significance to permit serious questioning of the practice of assessing pasture species as spaced plants. While there is a definite trend for some genotypes to show a good relationship between treatments, other genotypes do not, and selection under a spaced plant environment may result in a reduced, if not zero, response in sward production.

The conflicting results of some experiments examining the relationship between sward and spaced plant assessments (e.g., reported by Lazenby, 1957a) could be a feature of the genotypes used, apart from the techniques used in assessment. In spite of the fact that Lazenby's results (loc. cit.) do not entirely support his contention that the performance rankings of four ryegrass varieties were similar whether sown as spaced plants or swards, the genotypes used were fairly widely based and may not indicate the situation with different genotypes, or a narrower range of genotypes.

The conclusion reached with these results is neither that of Murphy's (1952), viz, "the breeder can use any of the ... methods of planting investigated for isolating selected plants which possess high yield potential", nor, on the other hand, that of Ahlgren et al (1945) who concluded that there was no relationship between estimated yields of the selections grown as spaced-planted rows and as swards. Here there is a relationship between performance rankings in each of the treatments, but there are also genotypes showing poor relationship. It is therefore concluded that spaced plants give an inadequate assessment of the expected performance of genotypes under higher levels of competition. It must be pointed out, however, that the conclusions reached with this material may not be applicable to either different species, or to similar species which possess levels of heterozygosity different from that of "Ariki".

Components of yield.

The components of yield of the November harvest, i.e., tiller number and tiller weight, show considerable genetic variation. The former shows a closer relationship to green yield than the latter, but the differences between genotypes in both treatments render tiller number *per se* an unsatisfactory method of assessing, either green matter production or competitive ability. Fertile tiller numbers, (which are fewer and easier to count than total tillers) are also an unreliable guide to green weight production.

Tiller numbers may have a greater use where index selection is practised (e.g., Glenday & Fejer, 1956).

Competition.

The examination of tiller counts and tiller weights, along with other characters which may be suggested as affecting the response of the plant to competition, fail to produce any conclusion. However, the marked response of progeny 9 to increased competition within the sward suggest that even between comparitively high levels of competition, genotype-by-competition interactions may occur. This seriously questions the suggestion forwarded by Lazenby & Rogers (1964a) that provided complete cover is achieved, non-sward densities afford the same competition met within in swards.

Further, it could be argued that even the close planting used in this experiment does not subject the plant to true sward conditions, notwithstanding the absence of other species, especially legumes.

Changes in plant type.

The interaction of genotype with environment for seed yield suggests that changes in the genotype of a population during seed increase generations, such as reported by Kelly & Boyd (1966), Cooper (1959), and Rumball(1970), can occur, and furthermore, the changes are likely to be different for a different spacing.

Limitations of the experiment.

"Ariki" ryegrass is essentially a permanent pasture species and the results of one year's growth may not indicate consequent performance. Genotypes with a large proportion of Lolium multiflorum genes may lack persistence, in spite of a high growth rate in the earlier stages of the experiment. The relative proportions of additive and non-additive genetic variance could well alter, if the trends indicated in the first three harvests are indicative.

As suggested above, even the close spacing used in this experiment may still be an inadequate simulation of the sward environment, where different species may also occur, and distances between plants may be very variable. Furthermore, differences due to soil fertility and moisture conditions may also result in genotype-by-environment interactions (Lazenby & Rogers, 1965b), as well as differences in cutting or grazing regimes (Lazenby & Rogers, 1965c).

Summary.

Ten Lolium [(multiflorum x perenne) x perenne] plants, eight of which are the elite parents of the variety 'Grasslands Ariki' Ryegrass, were diallel crossed. The progeny were planted out in two treatments, viz, a 2 ft. by 2 ft. spacing, representative of that commonly used by plant breeders at "Grasslands Division", D.S.I.R., and a 4-inch by 4-inch spacing in a simulated sward.

Significant genotype-by-treatment interactions occurred in all three green matter harvests during the first year of growth.

Vegetative tillers were counted at the second harvest (November) and fertile tillers were counted at the final harvest (December). While there were significant correlations between tiller number and yield, the results show that tiller counts were not a satisfactory technique to distinguish genotypes with potentially high sward productivity.

The proportion of fertile tillers that arose from the November vegetative tillers gave little insight either to production or competitive ability, nor could the time flowering commenced be related to either seed production or competitive ability.

An examination of the production in the sward treatments in the last harvest revealed that interactions of genotype with competition occur even at fairly high levels of competition.

Interactions of genotype with treatment also occurred for seed weight and time of flowering. The selection that may have occurred due to genotypic differences in seed production were related to plant type, as determined by after-math heading, leaf width and growth habit.

It was concluded that in spite of substantial genetic variation, further progress from selection in "Ariki" is likely to be limited, firstly by the levels of non-additive genetic variance, and secondly by the presence

of genotype-by-environment interactions that would not allow satisfactory estimates of the yield of a genotype in a sward from the yield, and components of yield of the genotype as spaced plants. It appears that the most efficient way of assessing the performance of a genotype in a particular environment is to place that genotype in that environment and assess its performance.

Appendix.

Missing plot estimation.

Yates (1933) gives a formula for fitting values to missing plots.

$$x = \frac{Bb + Vv - T}{(b - 1)(v - 1)}$$

where x is the fitted value to the missing plot, B and V are the block and variety totals respectively for the block and variety in which is the missing plot, b and v are the number of blocks and varieties respectively, and T is the grand total.

Where there are more than one missing plot, approximate values are inserted for all bar one missing plot for which the formula is used. The formula is then used on the second missing plot and so on until all the missing plots have been fitted with the formula. The process is then repeated and continued until all the values become constant.

Where there are a large number of missing plots, this can take some time. However, if each of the missing plots is expressed in terms of all the other missing plots, a series of simultaneous equations can be derived which, when expressed in matrix form, can easily be solved using an electronic computer with a matrix-inverting program.

The form of the matrix can be derived thus:-

x_{ij} is the missing plot in block B_i and variety V_j.

From the above formula

$$x_{ij} = \frac{B_i b + V_j v - T}{(b - 1)(v - 1)}$$

put $k = (b - 1)(v - 1)$

B_i is made up of the total of the extant plot values, plus the missing values. Similarly for V_j and T. Let R_i, L_j and G be the extant plot totals for block i, line j and the grand total respectively. Then we can express

x_{ij} as:-

$$x_{ij} = \frac{bR_i + vL_j - G}{k} + \frac{b}{k}\begin{pmatrix}\text{Sum of all missing} \\ \text{values in block i}\end{pmatrix} + \frac{v}{k}\begin{pmatrix}\text{Sum of all missing} \\ \text{values in line j}\end{pmatrix} - \frac{1}{k}\begin{pmatrix}\text{Sum of all missing} \\ \text{values}\end{pmatrix}$$

$$= \frac{bR_i + vL_j - G}{k} + \frac{1}{v - 1}\begin{pmatrix}\text{Sum of all missing values} \\ \text{in block i}\end{pmatrix} + \frac{1}{b - 1}\begin{pmatrix}\text{Sum of all missing} \\ \text{values in line j}\end{pmatrix} - \frac{1}{k}\begin{pmatrix}\text{Sum of all missing} \\ \text{values remaining}\end{pmatrix}$$

Therefore

$$x_{ij} - \frac{1}{v-1}(x_{i1} + x_{i2} + \ldots) - \frac{1}{b-1}(x_{1j} + x_{2j} + \ldots) + \frac{1}{k}(x_{pq} + x_{rs} + \ldots) = \frac{1}{k}(bR_i + vL_j - G)$$

$p, q, r, s, \neq i, j$

If this is repeated for each x, a series of simultaneous equations result, one for each missing plot, of the form

$$x_1 - \phi x_2 - \phi x_3 \ldots - \phi x_n = (bR_i + vL_j - G)/k$$

where $\phi = 1/(v - 1)$ where x_p is in the same block as x_1

$\phi = 1/(b - 1)$ where x_p is in the same line as x_1

$\phi = -1/k$ elsewhere.

The series of equations can be expressed in matrix form thus:-

$$\begin{bmatrix} 1 & -\phi_2 & -\phi_3 & -\phi_4 & \cdots & -\phi_n \\ -\phi_1 & +1 & -\phi_3 & -\phi_4 & \cdots & -\phi_n \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdots & \cdot \\ -\phi_1 & -\phi_2 & -\phi_3 & -\phi_4 & \cdots & -\phi_n \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{bmatrix} = \begin{bmatrix} (bR_1 + vL_1 - G)/k \\ (bR_2 + vL_2 - G)/k \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ \cdot \quad \cdot \quad \cdot \\ (bR_n + vL_n - G)/k \end{bmatrix}$$

where the ϕ's take values according to the x with the unit coefficient, and R_i and L_i correspond to the blocks and lines in which x_i appears, i.e., R_3 is not Block (3) but that block containing x_3.

As b in this experiment was 10, it was very quick to calculate (using a Canola 163) the RHS of the matrix equation. This had to be reduced by multiples of ten before being used on the computer as most of the LHS values are less than unity. Were this not effected, the computer program would "overflow".

The computer inverts the matrix and solves for all values of x which are printed out.

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