# THE IMPROVEMENT OF *ANDROPOGON SCOPARIUS* MICHX. BY BREEDING AND SELECTION

by

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# INTRODUCTION

The tame grasses and other cultivated forage crops have received the attention of plant breeders for a number of years, but the native grasses have been neglected until recently. This is because the need for such research has not been fully appreciated. The native grasses have always been here and it was assumed that they always would. Overgrazing and drought have so seriously depleted our ranges, however, that it is vitally essential that something be done to restore them. To this end the plant breeder can play an important part in the production of superior strains that are palatable to livestock, produce uniform growth, and yield enough seed to readily establish stands. They should also be leafy, aggressive, and persistent, especially when grazed, and produce a high yield of forage. Before he can do this, however, knowledge must be available on the variability and inheritance of the characters in the particular species with which he is working. With this aim in view, studies in such important native grasses as *Andropogon scoparius* were started in 1935 by the Agronomy Department of Kansas State College.

The prairie, in its original condition, was made up largely of the Andropogon association, of which *Andropogon scoparius* was one of the dominants, particularly in the drier uplands. The only large area of this association that remains is the Bluestem Pasture Region, occupying an area of about five million acres in eastern Kansas and extending some distance into Oklahoma. Prior to 1900 the grazing capacity of this region averaged approximately two acres per mature animal for the six month grazing season. By 1930 five acres were required and following the droughts of 1934 and 1936, it has been estimated that six or seven acres are needed to adequately pasture a mature cow or steer for the grazing period of April to September inclusive. The depletion has been particularly excessive in the smaller pastures.

For the revegetation of these depleted pastures and the return of cultivated land to grass the Andropogons have at least two distinct advantages. First, they are native to the region and are naturally the dominants of the prairie where they have become adapted to the growing conditions of the region through countless generations of natural selection. Second, they make the greater part of their growth during the summer (2) when the cultivated grasses produce little forage. In addition they are palatable, nutritious, and high yielders.

Seed of the prairie grasses has never been available in commercial quantities but a program of breeding and selection should make it possible to obtain seed in quantities and of a quality comparable to that of the cultivated grasses.

## DESCRIPTION OF THE SPECIES

Andropogon scoparius, commonly known as little bluestem and variously called prairie beardgrass, broom beardgrass, small feather grass, and broom sedge (although the last name should only be applied to Andropogon virginicus), is a perennial bunch grass with hairy flower heads. The specific name, scoparius, from scopa, a broom, means a sweeper and alludes to the resemblance of the bunches or tufts of stiff stems to a crude broom (47).

It is described by Hitchcock (18) as follows: "Plants green or glaucous, often purplish; culms tufted, from slender to robust, compressed, 50 to 150 centimeters tall, erect, the upper half freely branching; sheaths and blades commonly glabrous or nearly so, frequently sparsely pilose at their junction, rarely pubescent to villous throughout, the blades 3 to 6 mm. wide, flat; raceme 3 to 6 cm. long, mostly curved, the filiform peduncles mostly wholly or partly included in the sheaths, commonly spreading, the rachis slender, flexuous, pilose, sometimes copiously so; sessile spikelet 6 to 8 mm. long, scabrous, the awn 8 to 15 mm. long; pedicellate spikelet reduced, short awned, spreading the pedicel pilose." A form with villous foliage has been segregated as A. scoparius var. villosissimus Kearney, and a form with rachis and pedicels copiously villous, the rachis mostly nearly straight. A. scoparius neomexicanus (Nash) Hitch. is also described.

## LITERATURE REVIEW

The literature does not contain references to the genetic and breeding habits of Andropogon scoparius. The so-called tame grasses such as Phleum pratense, Lolium perenne, and Dactylis glomerata have been investigated by a number of workers. Some of this work shall be considered because it may have direct application to any grass breeding program. There is a wealth of material, however, on the taxonomy, adaptations, and ecological relationships of native grasses which deserves mention since it forms an important background for genetic research and the improvement of these grasses.

The species Andropogon scoparius is widely distributed over the temperate portion of North America. Hitchcock (18) states that its range extends from Quebec and Maine to Alberta and Idaho, and from there south to Florida and Arizona. It probably occurs in every state in the Union with the exception of Washington, Oregon, and California (47). It is the dominant grass in the upland portion of the prairie or tall grass region of the United States, occupying approximately twenty-six per cent of the area according to Steiger (42). Schaffner (37) and Weaver and Fitzpatrick (53) rate it as the second most important species of the prairie, *Andropogon furcatus* being the most important. According to Bruner (8), it is especially adapted to thrive in the upland prairies because of its adjustment to soils having a relatively low water content, making a much smaller demand than any of the other dominants. Its finely divided but extensive root system and a smaller growth above ground are contributing factors to its wide range. It is not only the most extensive upland species, but, according to Weaver and Fitzpatrick (54), occupies a portion of the area as a whole many times that dominated by *Andropogon furcatus*. Together with the latter it makes up over half the total vegetative cover of the Flint Hill or Bluestem pasture area (2). Its range, however, is not strictly limited to the prairie or tall grass region. In the Southwest it merges into the variety, *neomexicanus* (18), and is the dominant grass of the mixed prairie or transition area between the tall grass region and the true short grass plains. Albertson (1) reports that it has suffered great losses during the recent droughts in this region even where the short grasses were little harmed. Weaver and Albertson (52) find that losses of *Andropogon scoparius* during the drought of 1934 were considerably greater than that of *Andropogon furcatus*, losses of eighty to ninety per cent occurring where it was intermingled with the short grasses. Aldous (5) reports a loss of about fifty per cent of the Flint Hill's bluestems during the drought of 1934.

Andropogon scoparius is also the dominant in the sand hills of western Kansas (3) and on most of the steeper slopes in the western part of the state where grazing has not been severe enough to change the original stands of vegetation.

In the Bluestem area Andropogon scoparius is considered to be one of the most valuable of grasses, taking approximately the same rank in this respect as Andropogon furcatus. It is both palatable and nutritious during the leafy period and furnishes excellent grazing. It is not so highly esteemed, however, in some of the areas outside the Bluestem region. In Indiana it is mostly considered a weed, though grazing animals will eat it while it is young (11). In the North cattle avoid it preferring other grasses. Sarvis (35) reports that it is more or less avoided by cattle in the region of Mandan, North Dakota. This may be partly due to the stiff old stems that protect the young growth in the spring. Ranking the grasses of that region according to palatability, he places it sixth, with Bouteloua gracilis, Andropogon furcatus, Stipa comata, Koleria cristata, and Bouteloua curtipendula superior to it in the order given. In the Flint Hill area, however, it ranks with Andropogon furcatus at the head of the list in palatability and nutritive value (4). It is lower in palatability in the western half of Kansas, however (5).

Hubbard (20) recognizes three fairly well defined forms of Andropogon scoparius which he terms varieties. These include the common, widespread form occurring throughout central United States, a form indigenous to the Atlantic seaboard, and a villous-sheathed form with its center of distribution in Texas. The common form, however, merges into and inter-grades with the other two where their distribution areas overlap. House (19) also recognizes three forms of this species.

These forms correspond in general to Turesson's (46) ecotypes. Gregor and Sansome (14) conclude that there exist within a species definite habitat types. They agree with Turesson that these types have not necessarily arisen through chance isolation of variations, but represent the genotypical response of the species-population to a definite habitat. They further state that there may be phenotypic uniformity within these habitat types without complete genotypic similarity. Turesson (45) says essentially the same thing, "The habitat type, even if it appears to be quite homogeneous in its habitat, is made up of a number of individuals of which none may represent the genotype of another." He is of the opinion that while the differences in type may in part be due to the direct response of the individual plant to the environment, they are in the majority of cases due to the existence in the different habitats of different hereditary variations.

Jenkin (25), in his work with Lolium perenne, has noted that individual plants differ from one another even though derived from a relatively stable habitat but this variation is usually within quite narrow limits. Plants from different habitats conform to different general types. This is in complete agreement with the work of Turesson and Gregor and Sansome mentioned above.

The influence of environment, according to Stapledon (40), considered in its widest sense and embracing not only soil and climate but also methods of management (e.g., controlling the stock and the manner of using the fields as meadows or pastures) when long continued on the same general average, has a cumulative selective influence on the types which contribute to the vegetation of any particular area.

An explanation of the variability of Andropogon scoparius within the different habitat types may be the behavior of its chromosomes at meiosis. Church (10) finds that this species is an octoploid having the unusual complement of twenty-one bivalents and fourteen univalents. During the metaphase of the first division the univalents may be seen lagging in contrast to the bivalents all at the plate, and in the partly completed anaphase it can be seen that many of them never reach the plate. The diad stage may be observed with extrusions of chromatin at times being stranded in the space between the separating halves of the mother cell. Bivalents may occasionally lag with the univalents in the homeotypic division. The distribution of the univalents to the two daughter cells is random. Longeley (31) reporting chromosome numbers of various Andropogoneae states that the haploid chromosome number of *Andropogon scoparius* is 55/2, agreeing closely with Church (10). Hunter (21), however, states that the somatic chromosome number is forty.

Selfing reduces seed set in *Andropogon scoparius* just as it does in a number of other grasses that have been studied. Beddows (7) obtained 22.3 times as many seeds from open-pollinated heads of *Festuca elatior* as from those enclosed in bags. Trumble (44) obtained an average of only six seeds per head in selfed heads of *Phalaris arundinacea* as compared to ninety for open-pollinated heads. Hayes and Barker (15) found low seed set in selfed heads of *Phleum pratense*, but found marked differences that they consider to be due to genetic causes, for the correlation between the per cent of seed set under various conditions was high. Hayes and Clarke (16) obtained a correlation of 0.829 ± .033 between seed set of *Phleum pratense* under bags and in the open. This, they said, was an indication that seed setting under controlled conditions is due to genetic causes. They feel that selection within the selfed lines is a desirable method of breeding such cross-fertilized crops as timothy.

Jenkin (22) found many highly self-sterile plants in Lolium perenne and others that were rather highly self-fertile. He believes that self-sterility is one of the greatest obstacles in the way of improvement of grasses. Williams (56), on the other hand, feels that from the standpoint of forage crop improvement, self-fertility, on account of the marked loss of vigor that always accompanies inbreeding, must be regarded as nothing less than an unmitigated ill.

Valle (48) is of the opinion that it should be determined as soon as possible to what extent the selfing or close inbreeding method can be used in breeding the partially self-fertile plants to which the majority of herbage plants belong. If inbreeding has a generally enfeebling effect upon the growth of the progeny, as has been indicated in much recently published research, more suitable methods should be used. He says that particularly valuable results can be obtained by selection from breeding material for a particular character in accordance with the characters to which particular importance is attached in the district concerned. Evans (12) was able by continuous selection through several generations of open-pollinated Phleum pratense of the highly variable commercial types to develop strains having longer stems, earlier or later maturity, and better retention of green color in their leaves than the plants from which they were derived. The plants of many of these new strains showed a high degree of uniformity even though grown under natural conditions permitting open-pollination.

The vigor of open-pollinated crops is generally depressed in the generations following inbreeding. Familiar examples of this are corn and red clover. That the grasses are no exception to this is shown by the numerous reports of such loss of vigor following self-fertilization. Jenkin (22) found that cross-fertilization gave an increase of thirty-seven to two hundred twenty-four per cent in productivity over the inbred progenies in Lolium perenne. Lewitsky (30) reports depression of vigor in both Phleum pratense and Trifolium pratense following selfing. Calder (9) had similar results in Dactylis glomerata, and Nilsson-Leissner (34) found the same thing in red fescue (Festuca rubra), in comparing the inbred strains with the corresponding progenies from open-pollinations. Nilsson (33) observed great differences between individuals in general fertility, but showed the occurrence of self-sterility after inbreeding to be due to segregation of different factors directly causing a decrease in fertility or causing a depression in general vigor which again impedes fertility. He considers that the marked differentiation as regards fertility indicates the existence of comparatively few but effective genetic factors. He further states that selection in inbred families results in constant sterile types or in constant highly fertile types.

Williams (56) observed that loss in vigor in *Trifolium pratense* was greatest in the first generation following self-fertilization and less in each succeeding generation. Some families, however, retain their vigor to a greater degree than do others, none, of course, being as vigorous as the open-pollinated lines. The lines which retain their vigor are particularly valuable, he says, for the production of improved strains, as a large proportion of the plants in these more vigorous lines are strongly prepotent in regard to high yielding qualities when outcrossed. He feels that there are linked groups of growth factors which, inherited as units, may account for the prepotence of some plants.

The technique and the methods of grass breeding have received the attention of a number of workers. The details of the technique of hybridization (emasculation and pollination) have to be worked out for each species so will not be discussed. Jenkin (24) Vinall and Hein (49) give complete details of hybridization technique and of some of the problems connected with it. The actual breeding or improvement program may follow one of three lines, according to Stapledon (41), or all three may be employed more or less contemporaneously. The first is simply the finding and standardization of highly desirable regional strains. The next is the improvement of these strains by a method designed to increase the concentration of the more desirable forms of plants and decrease the concentration of those less desirable. The third is to proceed by strictly genetic methods employing artificial hybridization and progeny tests at all stages.

Grasses, according to Săulescu (36), are the most difficult crops to breed, chiefly because of the many sided demands made upon herbage plants; namely, cold resistance, disease resistance, longevity, quality, adaptability, and productivity. Great difficulties are attached to the testing of these characters. Stapledon (39) states that the economic value of a grass depends in the last resort not only on its palatability and nutritive value but equally on its ability to maintain itself and withstand the conditions of management superimposed upon it. All of these things then must be considered by the grass breeder and taken into account in the testing of his strains. The breeding methods that have been used by Jenkin (26) at the Welsh Plant Breeding Station are termed "strain-building" and consist in the selection of the original material, the selection of individual plants from this material that bear the characters desired, the blending of the desirable plants into strains, and finally testing and increasing them.

The breeding material at the Welsh Plant Breeding Station is originally selected from a large number of sources, particularly old, well-established pastures. Sufficient material is collected to represent the variations that occur naturally in the region concerned. From this mass of material the most desirable plants are selected by observation. These plants are then subjected to further selection, usually by the "tiller-row" method which emphasizes the plant type and habit of growth, to determine the ones that shall serve as the basis of the new strains. In some cases it is possible to establish a new strain on a single plant, but in most grasses the loss of vigor following such close inbreeding makes this method impractical. The theoretically perfect method would, in the case of each new strain, determine how many basically unrelated plants are required, but the amount of experimental work required for this would make it difficult to put into practice.

It may be necessary either to sacrifice some vigor for the sake of uniformity or some lack of uniformity for the sake of vigor. Where it is impossible to ascertain the gross genetical constitution of the basic plants by selfing, Jenkin (26) has worked out a system of diallel crossing in which each plant of a group tentatively selected to be the basis of his strain is crossed with each one of the others and the $F_1$ plants from each family then back-crossed with their parents. The suitable ones, those which combine well to make the strain, are selected and those less suitable are rejected. Meanwhile new plants are being brought in and tested, so "strain-building" becomes a continuous process in which the strain is constantly being improved though the general type is retained.

Too much stress can not be laid on the selection of a large amount of original breeding material so that the whole range of variations will be represented. According to Sylven (43) this variation or polymorphy within species is one of the most important foundations of plant breeding and is especially conspicious in cross-fertilized crops. During generations natural selection has created types of populations adapted to the various environmental conditions (the ecotypes of Turesson). During the course of selection originally heterozygous types have become homozygotized in a certain direction and gradually stabilized in a way suited to the growing purposes of that region. The change of type, appearing when such populations are moved out of their natural habitats, shows that in these cases homozygosity is not complete. Nature's selection has created stabilized ecotypes in which case the breeding work may consist mainly in the discovery of types most adapted to different growing purposes. The next step will then be the crossing of the different biotypes for the recombination of valuable characters.

Calder (9) employed a simplified form of strain-building which consisted in the planting of clons, each representing a single plant, for observation and testing. Some crossing was necessary to determine which plants cross well. These were then planted together in a sheltered field to cross naturally and thus build up a strain. This may give a strain that shows considerable variability but, in the words of Stapledon (41), "it does not necessarily follow that absolute purity either in plant type or in rigid retention of such type from generation to generation (under seed production) is essential or even, as such, desirable. A certain range of variability, provided the range is within a prescribed circle of excellencies, may be an actual advantage, having regard to such considerations as seasonal growth and the varied needs of the grazier. Absolute purity of plant type becomes a desirable feature in proportion as specialization is further and further intensified in the management of grassland. This tendency is toward progress and is, in fact, the modern tendency. The essential thing at the outset is, however, to guard against the deterioration of stocks and rather to eliminate the utterly undesirable plant types than to aim at too high ideals in the matter of excellence of type"

## MATERIALS AND METHODS

Andropogon scoparius is an extremely variable species. Not only does it vary greatly between localities but appears to be very heterozygous, for in any given locality there will be a rather wide array of forms. Some of the characters in which variations have been studied are: time of maturity, leaf area, height of plant, basal diameter, seed set, and germination. These are all important economic characteristics recognized by the farmer in their final expression, total yield of pounds of beef per acre from his land and recognized individually by the plant breeder as factors with which he must work to produce superior strains. They must all be considered in selecting the plants which are to be the basis of his strains.

Three generations of Andropogon scoparius have been included in this study. In 1935 the first generation of plants was set out for detailed study. In a sense these plants represented the variations that occur in the Flint Hill or Bluestem pasture area, while in reality considerable selection had already been practiced. The seed, from which the 1935 nursery was grown, was obtained from the most promising plants in the older observation plots of the grass nursery. The plants in these observation plots had all been grown from the seed of particularly promising plants occurring in nature. In the selection of this original seed such characters as tolerance to drought and heat, leafiness, and seeding ability were considered. The greater portion of the original seed was obtained from plants in a particularly droughty location along the southern exposure of a railroad right-of-way near Alta Vista, Kansas. Some seed from desirable plants found in other localities was also included. It was hoped that selections of this nature would have partially eliminated such undesirable characters as sparsity of leaves and poor seeding ability but that sufficient variability remained to furnish the basis of selection and breeding.

One hundred eighty plants, selected as the most desirable ones of several hundred seedlings, were transplanted to the nursery in May, 1935. They were spaced thirty by thirty inches in rows of twenty plants, in a plot, which shall be referred to as the 1935 nursery. In 1936 it was planned to grow at least twenty-five progeny from each of the original one hundred eighty plants. Seedling losses reduced this for a number of the lines, but in the majority of the cases twenty-five progeny were obtained. This 1936 nursery constitutes the second generation. Approximately fifty plants of the second generation were selected as being distinctly superior. The progeny of these make up the third generation which shall be referred to as the 1937 nursery.

In every case the plants have been grown as seedlings in the greenhouse from late February until May when they were transplanted to the nursery. The plants have been spaced thirty inches apart in each direction in order that they may attain their full development without being influenced by the competition of the neighboring plants and that they might easily be observed and studied. The spacing of thirty inches between rows permits cultivation with a small horse-drawn cultivator and reduce the amount of hand weeding necessary. During the drier periods of the summer the nursery was irrigated, water being supplied in furrows, so at no time have the plants been permitted to suffer from drought.

The plants have been carefully observed throughout their growing season and rather detailed field notes taken which shall be discussed, each under its own heading, as leaf area, time of maturity, etc. On the basis of these observations the outstanding plants have been selected to be the parents of the next generation. A number of heads on each of several particularly promising plants have been bagged so that the effect of selfing might be observed. A number of kinds of bags have been tried for this. The 18 by 36 inch parchment sleeves, however, have been found to be the most suitable material for enclosing the heads. Heads have been allowed to mature within the sleeves and harvested in October at the same time the open-pollinated seed is gathered. They are then taken into the laboratory where the caryopsis counts are made and the plants threshed during the winter.

Germination tests have been made during February. The 1936 seed was germinated on moist filter paper in Petri dishes. This gave rather higher germination percentages than would be expected in the fields, so the 1937 seed was germinated on soil in the greenhouse to simulate natural conditions. The seed was placed on moist soil and covered with a quarter of an inch of clean sand. After germination counts had been made the seedlings were transplanted to flats, later to be moved to the nursery.

The data obtained during the three growing seasons of 1935, 1936, and 1937 shall be discussed under the following heads: (1) general variability, (2) leafiness (in terms of leaf area), (3) quality, (4) basal diameter, (5) height of plant, (6) time of maturity, (7) setting of seed, (8) viability of seed (as shown by its germination), and (9) interrelationships.

## EXPERIMENTAL RESULTS

### General Variability

*Andropogon scoparius* is a widely distributed species but reaches its climax in the so-called tall grass region or true prairie and is less important in the mixed prairie region that lies between the tall grass area and the true short grass plains. In such a widely distributed species one would necessarily expect the existing wide variations. There seem to be rather definite habitat types corresponding to Turesson's (45) ecotypes, that have arisen as a result of natural selection over long periods of time. Strains (ecotypes or habitat types) from North Dakota, Nebraska, Kansas, Oklahoma. and Texas have been grown and observed in the nursery. In general the northern types are earlier, smaller, and less leafy than those from the south, while those from Kansas are intermediate in all three respects. In the 1937 season plants from northern Nebraska headed on an average of seventeen days earlier than those from Manhattan, Kansas, while the southern Oklahoma plants headed ten days later. Evans, Allred, and McConkey (13), working on this phenomenon in Phleum pratense, explained it on the basis of length of day requirements of the different types. According to their assumption the length of day required by the northern types for blooming is evidently reached at an earlier date than that required by those types from regions farther south. No experimental data on this subject is available for Andropogon scoparius however.

The variations in size and production of leaves are as striking as the time of maturity. Plates I, II, III, and IV show the general differences between the habitat types. The plants shown are all the same age and in their first season of growth. These variations are in accord with those found in Andropogon furcatus, Bouteloua gracilis, B. curtipendula, Panicum virgatum, Sorghastrum nutans, and a number of the tame grasses in the grass breeding plots of the Department of Agronomy at Kansas State College.

The above discussion does not imply complete uniformity within the habitat types but simply that there is a much

Plate I. *Andropogon scoparius* grown from Mandan, North Dakota seed. Photographed 10-6-37, Agronomy Farm Nursery.

PLATE I

Plate II. *Andropogon scoparius* grown from Kansas seed. Photographed 10-6-37, Agronomy Farm Nursery.

PLATE II

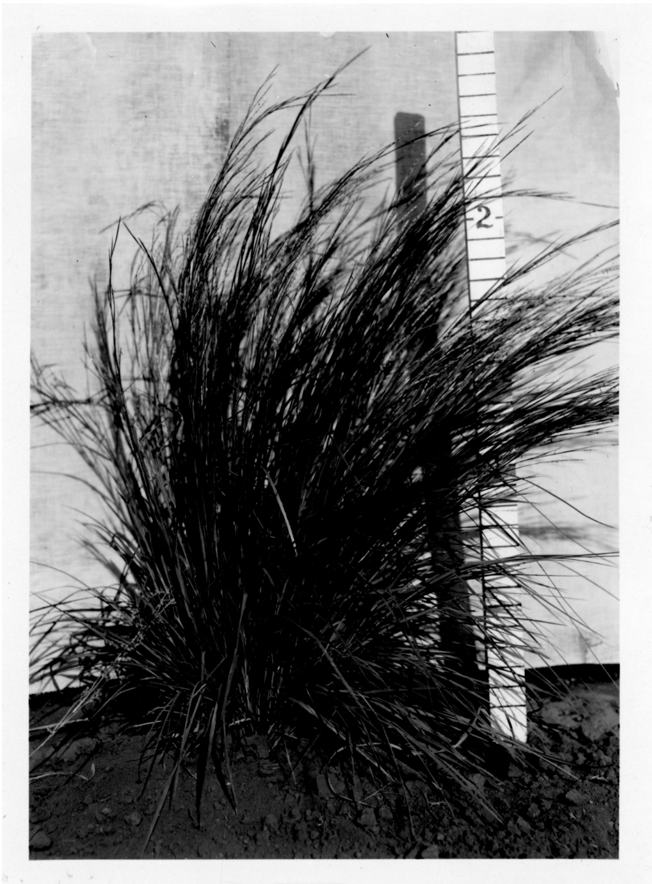


Plate III. <u>Andropogon scoparius</u> grown from Oklahoma seed. Photographed 10-6-37, Agronomy Farm.

PLATE III

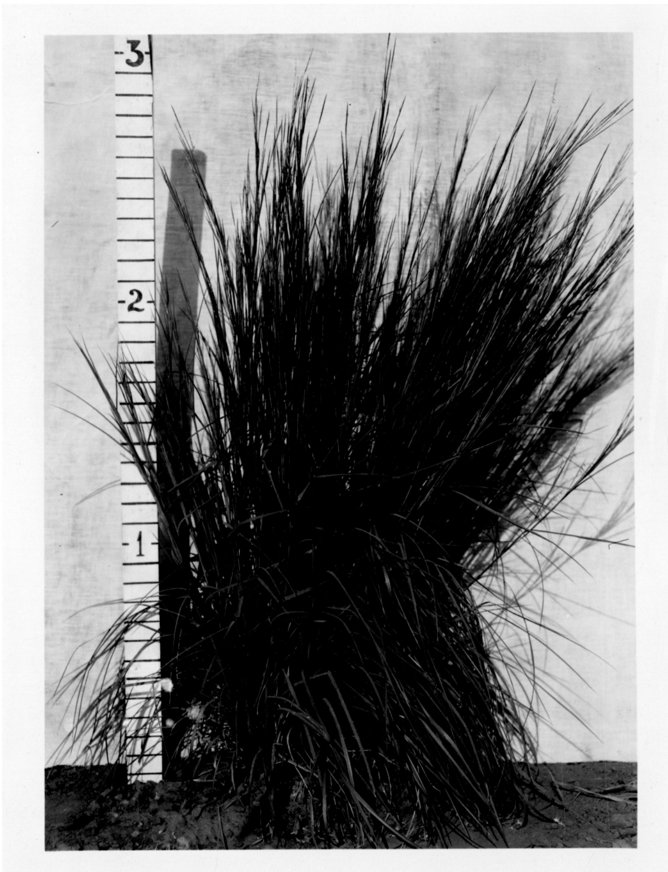


Plate IV. *Andropogon scoparius* grown from Texas seed. Photographed 10-6-37, Agronomy Farm Nursery.

PLATE IV

greater uniformity within than between the habitat types, and when the habitat types are being observed the great differences between them tend to obscure the smaller variations that occur within them. When the habitat types are studied individually, they are found to be quite variable within themselves, certain characters such as leafiness, time of maturity, height of plants, and seed set showing wide variations.

Keyser (27) observed similar variations in his preliminary studies on Bromus inermis. He found one hundred twenty-one distinct strains, a few of which proved to breed true for the character studied. Waldron (50), comparing clonal beds of varying plants of Bromus inermis, found striking differences. One clon, for instance, produced three times as much protein per unit area of land occupied as did some of the less productive ones. He reports similar differences for other characters. In New Zealand Hilgendorf (17) propagated clons of plants representing different types of Lolium perenne and Dactylis glomerata. They both exhibited wide differences when grown in like environments. These differences were considered by investigators to be proof of variability.

Diseases have not seriously affected Andropogon scoparius, but certain plants were noted to be affected by the rust, Puccinnia andropogonis, which also attacks Andropogon *furcatus*. The differences in rust infection among the plants indicate resistance in certain lines. The details of this question have yet to be worked out, however. Barker and Hayes (6) found rust resistance in *Phleum pratense* to be governed by a single factor, resistance being dominant.

*Andropogon scoparius* is a rather highly variable species varying not only with locality (ecotypes) but within the ecotypes to a certain extent, and from these variations it should be possible to secure types that are suited to the conditions of environment that they are expected to meet.

## Leafiness

Since it is the leafy portion of the grass plant that is preferred by the grazing animal, the area of leaf surface may be considered one of the most important factors of quality. On this assumption leaf area has been used as one of the bases of comparison of the various plants and plant families. It is the most important consideration in the selection of desirable types. It also supplies a means of measuring the quantity of forage produced by the plant without removing its foliage, thus allowing it to mature and produce a normal amount of seed.

Leaf areas were calculated for individual plants in the following manner. The length and width of ten leaves, taken at random on the plant, were measured and averaged. Average number of leaves per culm was then calculated for ten random culms of the plant, and the total number of culms on the plant counted. The product of average length of leaf, by average width of leaf, by number of leaves per culm, by total number of culms gave a value designated as leaf area of the plant. This value has failed to take into account the fact that the leaves are not rectangular but tapered, so it is greater than the true leaf areas of the plant. It has been felt that for purposes of comparison this value is satisfactory and that it would be unnecessary to calculate actual leaf area. In order to check this, however, the actual areas of one hundred representative leaves were measured with a planimeter. The actual areas were correlated with the values obtained by multiplying their length by width and found to give a correlation coefficient of $.9726 \pm .0054$. With such a high correlation between calculated and actual leaf areas, which indicates constant and definite relationship between the two, it is rather simple to obtain the actual leaf area from the value designated above as calculated leaf area. The factor for so doing has been found to be $0.8118 \pm .0587$. In other words, the actual leaf area is eighty-one per cent of the calculated area.

The plants have been found to vary greatly in total leaf area as illustrated in Plate V. Table 1 shows the variability in leaf areas of the 1937 crop of Andropogon scoparius for three generations.

Table 1. Leaf areas per plant (in square centimeters) of three generations of Andropogon scoparius. Measurements made in June, 1937.

| Season of Growth | | Range | Average |
|---|---|---|---|
| 3rd | 1935 nursery - | 14000-45000 | 30,700±7,500 |
| 2nd | 1936 " - | 2000-24000 | 10,000±3,700 |
| 1st | 1937 " - | 1000-15000 | 6,500±2,400 |
| 1st | 1937 " (selfed) | 1000-11000 | 6,400±2,200 |

If this variability in leaf area is due to the genetic constitution of the plant, as the results of selection seem to indicate, it may be used as a basis of improvement. The leafy types may be isolated and made uniform by selection and inbreeding, then if necessary they may be blended into strains.

Selection tends to decrease variability. Variations of leaf areas within selected families have been found by analysis of variance to be significantly less than the variations between these families, both in the second and third generation plants, representing first and second selections respectively. The F value is more highly significant in the third generation as shown in Tables 2 and 3.

It may be shown from these tables that through selection it is possible to eliminate the less desirable types and

Table 2. Analysis of variance of leaf areas of 21 families of <u>Andropogon scoparius,</u> selected once. (1936 nursery, 1937 crop).

| Source of Variance | | Degrees of Freedom | Sum of Squares | V | F | 1% Level |
|---|---|---|---|---|---|---|
| Total | (204-1) | 203 | 31,610,437 | 155,716 | | |
| Between families | (21-1) | 20 | 9,174,010 | 458,700 | 3.74 | 2.00 |
| Within families | | 183 | 22,436,427 | 122,603 | | |

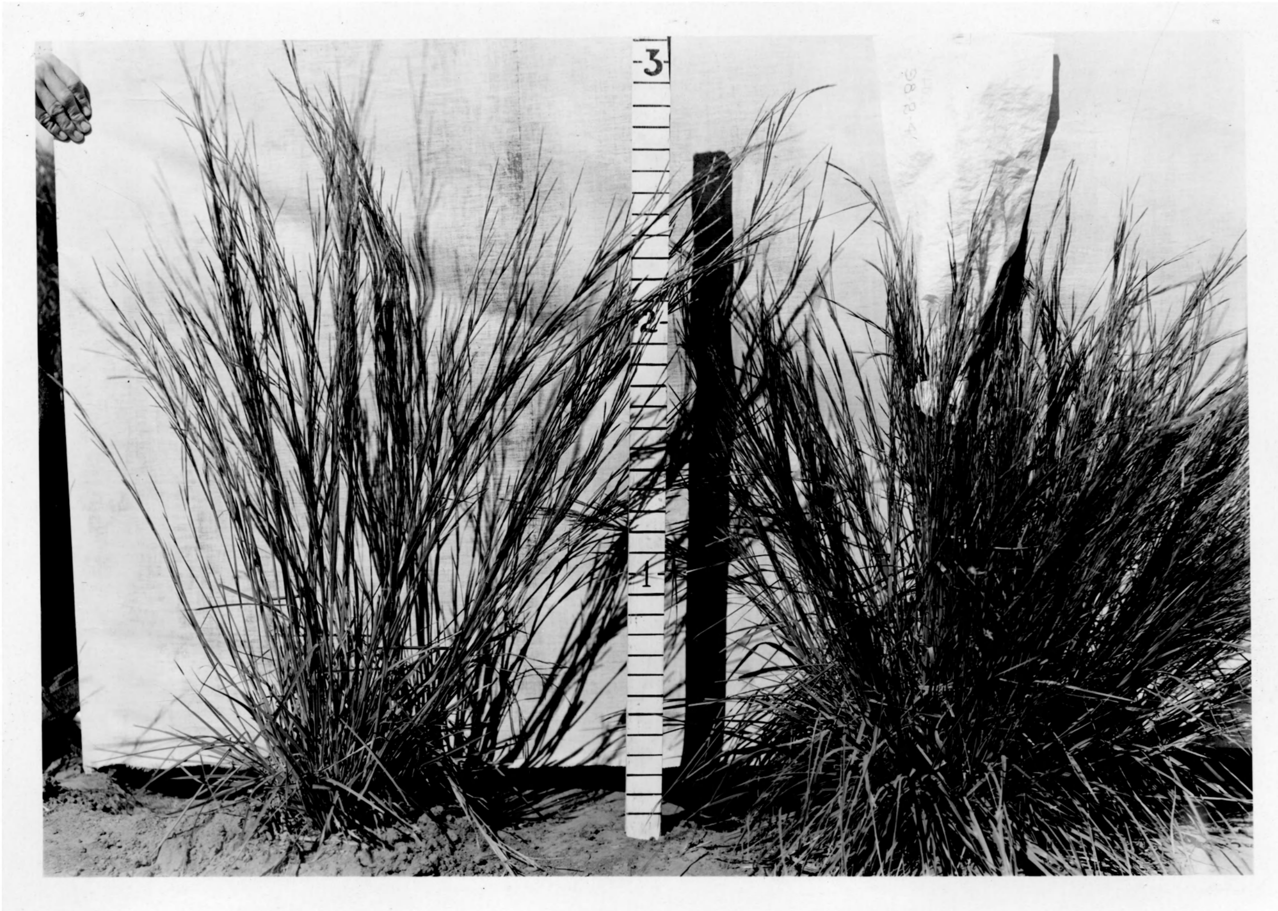
Table 3. Analysis of variance of leaf areas of 28 families of <u>Andropogon scoparius</u>, selected twice. (1937 nursery, 1937 crop).

| Source of Variance | | Degrees of Freedom | Sum of Squares | V | F | 1% Level |
|---|---|---|---|---|---|---|
| Total | (280-1) | 279 | 14,453,259 | 51,803 | | |
| Between families | (28-1) | 27 | 6,345,863 | 235,032 | 7.3 | 2.06 |
| Within families | | 252 | 8,107,396 | 32,172 | | |

establish a population in which only the desired ones appear. Hybridization may be necessary to combine characters from two or more lines, but first it is essential that the desired characters be established through selection and selfing. In many grasses selfing can not be practiced without serious losses of vigor. Too few selfed plants have been obtained in <u>Andropogon scoparius</u> to say definitely whether

Plate V. *Andropogon scoparius*, first season of growth, showing variations in leafiness that occur in the local ecotype. Photographed 10-6-37.

PLATE V



or not its vigor is affected by selfing, but the average leaf area of forty-eight selfed plants that were available for measurement was no different than the average of the open-pollinate population (see Table 1). Should selfing prove impractical, however, some other method of inbreeding can be practiced.

## Quality

No satisfactory measure of quality of *Andropogon scoparius* has yet been worked out. Total leaf area and the ability of the plant to remain green and leafy over a long grazing season are both factors in the quality of a pasture plant and shall be discussed under separate headings. There are, however, differences that can not be measured in terms of inches, or number of days, or pounds, but can be detected by occular observations by one who is thoroughly familiar with the grass. There are differences in the texture of the foliage, certain plants having rather erect harsh leaves, others having soft lax foliage. There are slight variations in color and pubescence and in ratio of stem to leaf, and general habit of growth to which no definite units of measure can be applied, but which are very definitely factors of quality, and must be considered in making one's selections. The trained observer will be able to detect these differences and to make selections accordingly.

Grazing tests are a satisfactory method by which to measure quality in that it will affect the palatability and thus affect yield on the basis of pounds of beef per acre, but as yet none of the lines have been increased to the extent that they may be tested under pasturing conditions. The ultimate selection of strains will, however, have to be based on their reactions to grazing.

## Basal Diameter

*Andropogon scoparius* is a bunch grass, producing neither stolons nor rhizomes, and hence can not spread vegetatively as can so many of the native grasses. The bunches may attain considerable size, however, and thus cover a relatively large part of the ground surface of the area occupied by the species. Measurements of the basal diameter of three generations of this species show a rather marked variation.

Table 4 is a summary of the average basal diameters of three generations of *Andropogon scoparius*, showing the range of variability and the averages.

Table 4. Basal diameters (in inches) of three generations of Andropogon scoparius (1937 crop).

| Season of Growth | | | Range in Diameter Inches | Average |
|---|---|---|---|---|
| 3rd | (1935 nursery) | | 7.0 to 10.0 | 8.0±.71 |
| 2nd | (1936 " ) | | 3.0 to 7.0 | 4.9±.87 |
| 1st | (1937 " ) | | 1.0 to 5.0 | 2.8±.25 |
| 1st | (1937 " ) | (Selfed) | 1.0 to 4.0 | 2.75±.67 |

Analyses of variance, which show a tendency toward uniformity within families, indicate that basal diameter is an inherited characteristic. Analyses of variance for the 1936 and 1937 nurseries, representing second and third generations respectively, are shown in Tables 5 and 6. The plants in these nurseries have been permitted to cross pollinate freely so the selections have been in entirely open pollinated lines. Too few selfed plants have been obtained to make any valid analyses of the effect of selfing, but it is indicated that selfing has not reduced the basal diameter.

Table 5. Analysis of variance of basal diameter, second generation *Andropogon scoparius* plants. (1936 nursery, 1937 crop).

| Source of Variance | Degrees of Freedom | Sum of Squares | V | F | 1% Level |
|---|---|---|---|---|---|
| Total (214-1) | 213 | 363 | | | |
| Between families (21-1) | 20 | 264 | 13.2 | 25.88 | 2.12 |
| Within families | 193 | 99 | | | |

Table 6. Analysis of variance of basal diameter of twenty-eight families of third generation, *Andropogon scoparius* plants. (1937 nursery, 1937 crop).

| Source of Variance | Degrees of Freedom | Sum of Squares | V | F | 1% Level |
|---|---|---|---|---|---|
| Total (280-1) | 279 | 111.0 | 0.3978 | | |
| Between families (28-1) | 27 | 23.8 | 0.8815 | 2.55 | 2.06 |
| Within families | 252 | 87.2 | 0.3460 | | |

It will be seen from these tables that while there is considerable variability in basal diameter, the greater part of the variability is between families rather than within them, and that the progeny of a single plant tend to be more like one another than like the whole population. It may be assumed, then, that selection, even in open-pollinated lines, may be a desirable means of obtaining relatively uniform types.

Number of culms per plant is so closely associated with basal diameter that it shall be considered under the same heading. It will be seen from Table 7, which shows culm counts for three generations of *Andropogon scoparius*, that these two characters parallel one another very closely.

Table 7. Number of culms of three generations of *Andropogon scoparius* (1937 crop).

| Season of Growth | Number of Culms Range | Number of Culms Average |
|---|---|---|
| 3rd (1935 nursery) | 180 to 844 | 491±118 |
| 2nd (1936 " ) | 40 to 445 | 188±71 |
| 1st (1937 " ) | 31 to 262 | 107±40 |
| 1st (1937 " ) (Selfed) | 11 to 165 | 110±32 |

It is interesting to note that from the standpoint of number of culms per plant there is no evidence that selfing reduces vigor in *Andropogon scoparius*, for it will be seen that the numbers of culms per plant are approximately equal in both selfed and open-pollinated plants of the 1937 nursery. This can not be taken as final proof that selfing does not affect vigor of growth, however, for as yet the data are too incomplete to make definite statements concerning this question.

## Plant Height

No attempt has been made to use plant height as a basis of selection of the desirable families. Considerable variability has been observed and measured in this character, however. Plant height data are available for three generations as shown in Table 8.

Table 8. Average heights (inches) of three generations of Andropogon scoparius, (1937 crop).

| Generation | Range (Inches) | Average Height in Inches |
|---|---|---|
| First (1935 nursery) | 20 to 38 | 29.8±3.3 |
| Second (1936 nursery) | 11 to 31 | 22.5±3.2 |
| Third (1937 nursery) | 11 to 29 | 21.2±3.2 |
| Third (Selfed)(1937 nursery) | 10 to 24 | 20.0±3.1 |

These measurements were made during the period of rapid vegetative growth before the flowering culms had begun to appear. They represent height of plant to the tip of the leaves held upright. It will be seen that there is considerable variability in the population as a whole.

In contrast with this general variability in plant height, it has been observed that a rather marked uniformity exists within the progeny of individual plants. Progeny of twenty plants of the 1936 nursery have been compared by analysis of variance with the results shown in Table 9.

Table 9. Analysis of variance of plant heights of second generation <u>Andropogon scoparius</u> plants. (1936 nursery, 1937 crop).

| Source of Variance | Degrees of Freedom | Sum of Square | V | F | 1% Level |
|---|---|---|---|---|---|
| Total (179-1) | 178 | 4684 | 26.31 | | |
| Between families (20-1) | 19 | 2125 | 111.84 | 6.95 | 2.00 |
| Within families | 159 | 2559 | 16.09 | | |

A high probability is indicated that a greater variation exists between groups of progeny than within. In other words, there is a tendency for the plants to produce more or less uniform offspring.

Plants in the 1936 nursery which were distinctly superior in quality were selected as the parent material for the next generation. Each is represented by a group of its offspring in the 1937 nursery. No particular attention was paid to plant height in this selection except to avoid extreme types, yet analysis of variance of twenty groups of progeny of the 1937 nursery show a significant trend toward uniformity within groups. Only the better plants had been selected from the 1936 nursery, extremely tall or short types being eliminated. There is still as much variation between groups of progeny in the 1937 plants as in the 1936 plants, but the variability within groups of progeny has been greatly decreased by selection. This is shown in Table 10.

Table 10. Analysis of variance of plant height of third generation <u>Andropogon scoparius</u> plants. (1937 nursery, 1937 crop).

| Source of Variance | Degrees of Freedom | Sum of Square | V | F | 1% Level |
|---|---|---|---|---|---|
| Total (280-1) | 279 | 1167 | 4.18 | | |
| Between families (28-1) | 27 | 944 | 34.96 | 39.28 | 1.88 |
| Within families | 252 | 223 | 0.89 | | |

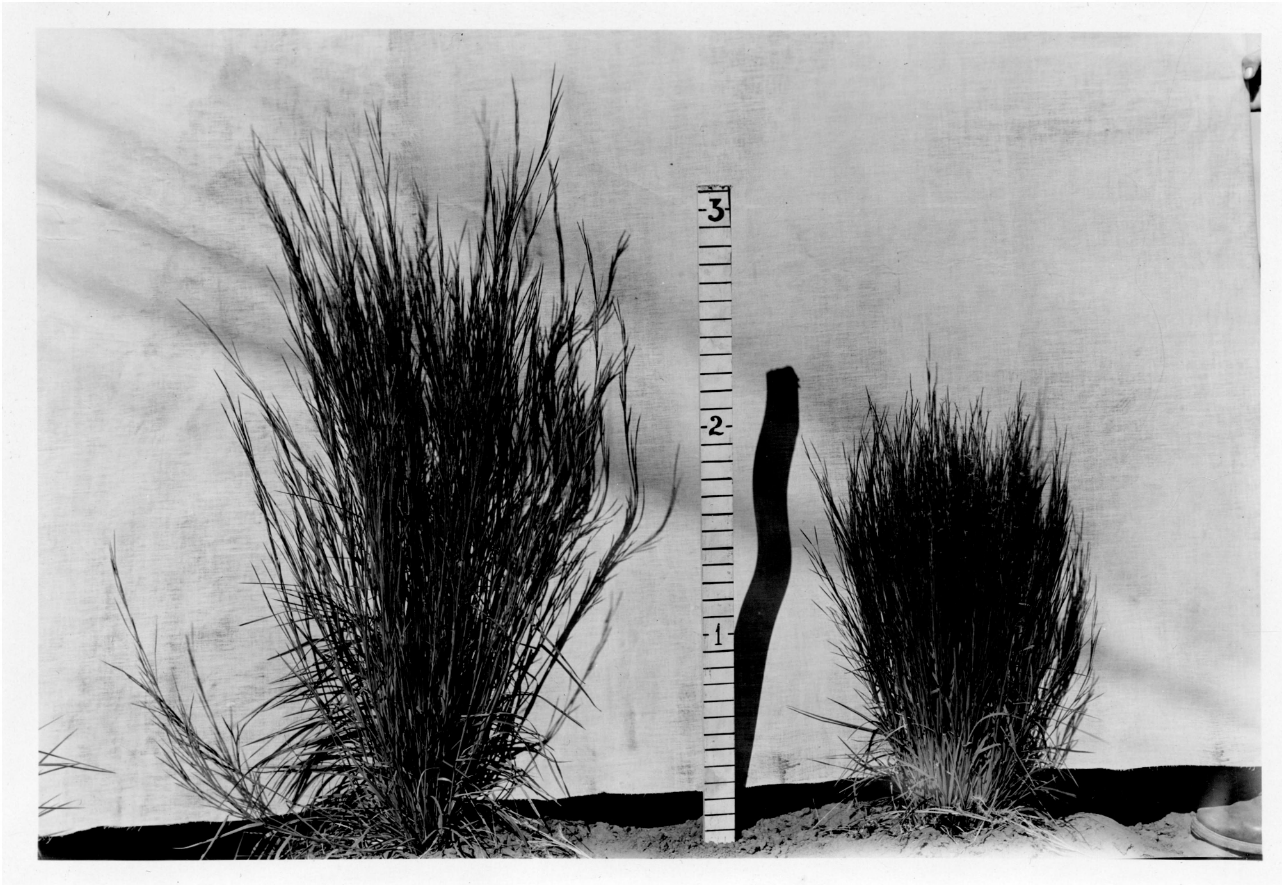
These data may be considered proof that plant height is an inherited characteristic, and that one may through selection obtain tall or short types as the need may arise.

It has already been suggested that self-fertilization may not have as great a depressing effect on plant vigor in <u>Andropogon scoparius</u> as in certain other grasses. This is further indicated by the plant height measurements of the forty-eight $S_1$ plants in the 1937 nursery. Their average height was $20.0 \pm 3.1$ inches as compared to $21.2 \pm 3.2$ inches for the open-pollinated plants, a difference of only 1.2 inches in favor of the open-pollinated plants.

Since so few selfed plants were available for observation, this can not be considered conclusive evidence that inbreeding does not decrease vigor, yet it seems to indicate

Plate VI. Variations in height of plants in local *Andropogon scoparius*. Plants in their first season of growth. Photographed 10-6-37.

PLATE VI



that such is the case. A larger selfed population will be available for measurement in the next generation from which more conclusive data may be had. Should it be shown that selfing or other forms of close inbreeding do not reduce vigor in Andropogon scoparius, they will be a valuable means of breeding improved strains.

## Time of Maturity

Time of maturity is an important consideration in the breeding of a pasture grass. It is desirable that the plant remain in the leafy, vegetative stage during as much of the grazing season as possible, but also that it mature and set its seed before frost. Andropogon scoparius does this fairly well, yet certain plants have been studied that remained leafy much longer than others and still produced a good seed crop. Thus, one of the bases of selection has been late maturity with the hope that the average heading date could be delayed somewhat.

It is necessary that a rather definite stage in the development of the plant be used as the basis of comparison when time of maturity is being measured. Heading date is often used in this manner, but one or two culms on an occasional plant may head precociously. After inflorescences have begun to appear on four or five culms, however, heading has definitely begun. On the basis of these observations the day that five culms first show inflorescences has arbitrarily been designated as heading date, or date of maturity. The plants in all three generations were observed daily during the period of heading so it has been possible to obtain accurate data on their time of maturity. These data are tabulated in Table 11.

Table 11. Average heading dates of three generations of Andropogon scoparius, season of 1937.

| | Average heading date |
|---|---|
| 1935 nursery (first generation) | Aug. 10 ±14 days |
| 1936 nursery (second generation) | Aug. 8 ±13 days |
| 1937 nursery (third generation) | Sept. 2 ±5 days |

The first generation represents plants that were selected as representative of the variations that occur in nature so their heading date is comparable to that of the wild populations in the vicinity of Manhattan, Kansas. The second generation (1936 nursery) are the progeny of these plants. Since all are represented it would not be expected that the average heading dates would differ. Actually, they differed by an average of only two days. The third generation (1937 nursery), however, represents plants whose parents were the late maturing ones of the 1936, or second generation. Their average heading date was September 2, more than three weeks later than that of the parent plants. The late date of maturity of the third generation plants may be partly accounted for by the fact that they were young plants in their first season of growth. This might have been the cause of the delay in their maturity, but there is no evidence to show that it could cause them to be so much later. It will be seen that the standard deviation of the heading date has been reduced from fourteen and thirteen days in the first and second generations, respectively, to five days in the third generation. This would indicate that greater uniformity has resulted from selection and that the plants are actually later than the former generations and the wild population.

A further check on the variability in heading date of several families of Andropogon scoparius has been made by the method of analysis of variance outlined by Snedecor (38). These families are all of local stock, progeny of the original one hundred and eighty plants in the 1935 nursery. Two generations have been studied. Table 12 shows the analysis of variance of twenty-one families of the 1936 nursery. Each of these families represents the progeny of a single plant of the 1935 nursery. They were not selected for late maturity but rather to see if there were any marked uniformity within the progeny of individual plants as compared to the total population. That there is such uniformity is shown by the high F value obtained in the analysis of variance.

Table 12. Analysis of variance of heading dates of twenty-one families of Andropogon scoparius, grown from open-pollinated seed. (1936 nursery, 1937 crop).

| Source of Variance | | Degrees of Freedom | Sums of Squares | V | F | 1% Level |
|---|---|---|---|---|---|---|
| Total | (203-1) | 202 | 35,196 | 174 | | |
| Between families | (21-1) | 20 | 9,167 | 458 | 3.20 | 2.00 |
| Within families | | 182 | 26,092 | 143 | | |

The third generation (1937 nursery) consists of the progeny of individuals selected from the 1936 nursery as being later in time of maturity than the average of the population as a whole. These were also compared by analysis of variance (Table 13). Although the population as a whole was less variable than the parent generation, the variability within families was found to be significantly less than between families.

Table 13. Analysis of variance of heading dates of twenty-one families of Andropogon scoparius. (1937 nursery, 1937 crop).

| Source of Variance | | Degrees of Freedom | Sums of Squares | V | F | 1% Level |
|---|---|---|---|---|---|---|
| Total | (210-1) | 209 | 7,911 | 37.85 | | |
| Between families | (21-1) | 20 | 4,635 | 231.75 | 13.37 | 2.00 |
| Within families | | 189 | 3,276 | 17.33 | | |

From the above tables it may be seen that *Andropogon scoparius* may be made later and more uniform by selection in open-pollinated lines. Further selection should make it possible to establish lines that are relatively stable not only in regard to heading date but for other characters as well.

## Setting of Seed

Ability to produce seed is one of the important considerations in the improvement of pasture grasses, especially grasses like *Andropogon scoparius* that have the bunch type of growth. Under natural growing conditions these species can not spread vegetatively by stolons or rhizomes, but must depend solely on seed for their propagation.

In nature the seeding habit of *Andropogon scoparius* is variable and is influenced by a number of factors, chiefly climatic. It seeds abundantly in favorable seasons but drought and overgrazing reduce and may even prevent seeding. High temperatures at flowering time also reduce it. This is indicated by the fact that early plants which pollinate during very hot dry weather have great numbers of blasted heads. Seed is produced only in the later maturing heads which have escaped the hot weather.

There is a popular belief that the bluestem grasses set seed only once in seven years. There is no basis for this belief, as the plants in the breeding nursery have set seed each year for six or more years. During the dry summer of 1936 a few plants less favorably situated in respect to soil moisture failed to seed. In the irrigated portion of the nursery none have failed to head but several very late plants were frosted before seed could mature.

The problem of the setting of seed has been studied on the basis of the percentage of spikelets that produced caryopses, since it has not been found possible to make counts of the total number of spikelets per plant. An attempt was made to separate the heads from the leaves and stems of mature dry plants in order to obtain relative weights of each, but this was found to be impractical because of the great numbers of fine stems and branches, so estimates of seeding ability have been made on a comparative basis by observation. Plants have been classed as good, medium, or poor seeders according to the number of heads there appeared to be on the plant. In the selection of plants for the next generation seed, those classed as poor have been discarded even though they were rather promising in other respects.

Detailed observations have been made on seed setting, i.e., the percentage of the fertile spikelets that produced seed. This percentage has been determined by counting the number of caryopses in three lots of one hundred spikelets picked at random from the plant, and averaging these three counts.

Table 14 shows the seed set of the 1937 crop of seed.

Table 14. Seed set of third generation plants. (1937 nursery, 1937 crop).

| Plants | Seed Set in Per Cent |
|---|---|
| Open-pollinated, all three generations | 63.12±18.7 |
| Open-pollinated in 1937 (grown from seed selfed in 1936) | 55.84±19.1 |
| Selfed in 1937 (grown from open-pollinated seed) | 6.24±4.2 |
| Selfed in 1937 (grown from seed selfed in 1936) | 6.77±5.3 |

Set of seed was found to be greatly reduced by enclosing the heads in any sort of bag for the purpose of self-fertilization. Malte (32) found that grass pollen is, in general, very sensitive to humidity, refusing entirely to germinate under very humid atmospheric conditions. During the summer of 1936, a number of types of bags were tried in the field. During the very hot months of July and August, no seed was set under any of the bags, while very little was set by the unbagged heads. In the fall, however, a few seeds were produced under cloth bags large enough to cover several culms. In 1937 no attempt was made to bag the heads until late in August after the hottest weather was past. Eighteen by thirty-six inch parchment sleeves were slipped over five or six culms at the time the heads were emerging from the sheaths. The sleeves were folded over twice at the top and stapled to the top of the stake. The bottom was tied around the plant and fastened to the stake. The parchment paper was stiff enough that the sleeve did not collapse but allowed a considerable space about the plant for air. Plate VII shows the manner of attaching the bag.

In spite of any precautions that have been taken, the set of seed in the bags has always been greatly reduced. The average number of seeds per hundred spikelets in the bagged heads was about six to seven as compared with fifty-five and sixty-three for the open-pollinated heads. Wolfe (57) obtained similar results with orchard grass. He enclosed whole plants in cotton bags, single heads in paper bags, and several heads in paper bags. All three gave low seed set, averaging from four to fifteen per cent as compared to forty-five per cent in open-pollinated heads. Trumble (44) working with Phalaris sp. obtained an average of six seeds per head under bags and ninety on the open-pollinated heads.

This reduction in set of seed may be due to the abnormal conditions existing within the bag, or it may be that since Andropogon scoparius is naturally a wind pollinated species, it demands foreign pollen. It has been noted that in bags which had accidentally become torn, or which had been injured by grasshoppers, the seed set was practically

Plate VII. Showing manner of attaching parchment sleeves for selfing.

PLATE VII

normal. It was impossible, however, to determine whether or not the bag had been torn before pollination had taken place, so it is not known whether these plants have actually been selfed or simply wind pollinated.

No apparent difference could be noted in the set of seed of plants grown from selfed seed and those grown from open-pollinated seed, see Table 14. In other words, the selfed plants set seed as well as those from open-pollinated seed. This agrees with Williams' (55) findings in red clover. In his lines of red clover seed set was not reduced even after four or five generations of self-fertilization.

If this holds true after several generations of self-fertilization, it will be possible to employ this method of inbreeding and still secure seed. This will materially aid in any breeding program that might be undertaken.

## Germination

Germination is important because of the obvious relationship it bears to securing a stand of grass. As a rule, the germination of *Andropogon scoparius* is fairly high but considerable variation has been noted. Germination percentage of the 1936 seed crop varied from 42% to 89% with an average of 63.5±13.4 in the case of the open-pollinated seed. Selfed seed showed a somewhat lower germination percentage, the average being 25.8±23.4 with a range of from

0% to 100%. Only seven seeds were available from the one plant which germinated 100%, so these results can not be considered of any significance. The average of 25.8% was calculated from a total of 537 seeds, which was all the selfed seed obtained from the 1936 crop. In nine of the thirty-one selfed plants that were tested none of the seeds germinated, while only five plants germinated better than 50%. The difference in germination percentages between open-pollinated and selfed seeds, which was 37.7±27.0 in favor of the open-pollinated seed, can not be considered significant in view of the standard deviation.

The 1937 seed crop, germinated in February 1938, showed a slight, though not significant, advantage for the selfed seed over the open-pollinated. The percentages were 18.5±12.8 and 30.5±24.4 for the open-pollinated and the selfed seed respectively, with a difference of 12.0±27.2. These indicate that selfing does not affect germination. This agrees with the work of Jenkin (23), who found the germinating capacity of <u>Lolium perenne</u> much less affected by selfing than the vigor of growth; and with the work of Wolfe (57), who found no significant differences in germination of selfed and open-pollinated seeds, the percentages being 47.1±4.27 and 50.4±4.36 respectively.

In the 1936 tests it was noted that some plants seemed to germinate more rapidly than others, so in the 1937 tests counts of the seedlings were made at seven days after planting and again at two weeks. Most of the seedlings had appeared above ground at the end of seven days but a number of them continued to appear during the second week. The results of these observations are summarized in Table 15. Open-pollinated seed is compared with seed selfed once and with seed selfed for two generations. There are no significant differences between the three groups, but within each group there are rather wide differences in rate of germination.

It is not known how these variations are inherited, but they must be considered in any breeding program, for the rate of germination may mean the difference between success and failure to produce a stand due to the water-root relations. The ability to germinate quickly and establish a root system will enable the seedling to better compete with weeds and other grasses. This is especially true in the bluestem grassland areas where water is usually the limiting factor. Weaver (51) states that grasslands are relatively dry lands and that drought, at least in the surface soil, is always eminent. It is thus necessary for a seedling to make immediate and extensive contact with deeper, moister soil. In denser stands of seedlings differences of an inch or two in root length, representing the development of but one or two days, may easily become decisive, both as to the absorption of water and the consequent rapid growth that results in

Table 15. Germination of the 1937 seed crop of Andropogon scoparius (third generation), comparing open-pollinated seed with $S_1$ and $S_2$ seed at seven and fourteen days after seeding.

| | Germination Percentages | | | | | |
|---|---|---|---|---|---|---|
| | Seven Days After Planting | | Fourteen Days After Planting | | Differences | |
| | Range | Average | Range | Average | Range | Average |
| Open-pollinated | 0-49% | 11.46±10.67 | 0-57% | 18.45±12.88 | 0-32 | 6.98±4.64 |
| Selfed once (1937) | 0-100% | 11.77±12.72 | 0-100% | 20.48±18.60 | 0-42 | 9.71±7.97 |
| Selfed twice (1936-1937) | 0-100% | 20.83±20.64 | 0-100% | 30.52±24.36 | 0-38 | 10.67±9.76 |

overtopping. Hence, it is desirable that the seed germinate quickly and establish a vigorous seedling.

## Interrelationships of Characters

It has been observed that rather definite relationships exist between certain of the vegetative characteristics of *Andropogon scoparius*. A rather detailed study of the correlations existing between pairs of characters has shown that not only do these relationships exist, but that they follow definite trends.

Two factors may be considered to influence these trends, the effect of selection, and the effect of the age of the plant, that is, changes brought about during its life cycle. These two effects, however, can not be separated with the available data. Several years' results would be required to do this.

Table 16 is a summary of the interrelationships of the characters studied, showing correlation coefficients for three generations of plants for the crop season 1937. Each pair of data shall be discussed under its own heading.

Table 16. Correlation coefficients showing the relationships that exist between certain characters in <u>Andropogon scoparius</u>. The data are from the 1937 crop of three generations of <u>Andropogon scoparius</u>.

| | | No. of Culms | Height to Tip of Leaf | Leaf Area | Time of Maturity |
|---|---|---|---|---|---|
| Basal Diameter | 1935 nursery | .25±.06 | .69±.04 | .24±.06 | |
| | 1936 " | .52±.04 | .40±.05 | .50±.04 | |
| | 1937 " | .68±.03 | .51±.04 | .67±.04 | |
| No. of Culms | 1935 nursery | | | .46±.12 | |
| | 1936 " | | | .79±.02 | |
| | 1937 " | | | .87±.01 | |
| Height to Tip of Leaf | 1935 nursery | | | .56±.10 | |
| | 1936 " | | | .43±.04 | |
| | 1937 " | | | .31±.05 | |
| Leaf Area | 1935 nursery | | | | .26±.05 |
| | 1936 " | | | | .18±.06 |
| | 1937 " | | | | .003±.05 |

<u>Basal Diameter to Number of Culms</u>. It is reasonable to assume that larger plants have the greater number of culms, yet it can be seen that the ratio between these characters is not a constant. As the plant grows older crowding and competition may reduce the correlation between number of culms and the area occupied by the plant. On the other hand, it has been shown that selection tends to increase uniformity in both leaf area and basal diameter, and it appears to have made these two characters correlate more closely.

<u>Basal Diameter to Height of Plant</u>. The high positive correlations show a distinct relationship between basal diameter and height of plant but no trend from one generation to the next is indicated, neither is there any trend according to the age of the plants nor any evidence that selection has affected the relationship between these two characters. Since these characters are both expressions of the general vigor of the plant, their correlation is in accordance with expectations. Plants with a large number of dominant growth factors would be both taller and greater in diameter than those with fewer dominant growth factors.

<u>Basal Diameter to Leaf Area</u>. In each succeeding generation of plants the correlation of basal diameter to leaf area has increased. It is probable that in young plants there is a closer relationship between these two characters than in older plants, due to the fact that competition tends

to keep the central part of the older plants thinned out. It is difficult to see, however, how this could account for the great difference in correlation coefficients shown in the three generations studied, yet there is not sufficient data to show that it is definitely due to selection of certain types and the elimination of others.

Number of Culms to Leaf Area. This correlation parallels that of basal diameter to leaf area since number of culms and basal diameter are so highly correlated. It shows that in older plants the relationship between number of culms and leaf area is not as great as in young plants.

Height of Plant to Leaf Area. The trend shown by the data indicates an increasing correlation of these characters with increase in age. The reason for this is not clear. It may be, however, that selection has changed the relationship existing between the two characters. One of the aims in selection has been the elimination of those types with small leaf areas, while there has been no attempt to change the height of plants. If the less leafy types have been eliminated and greater uniformity of type established, while the height remains as variable as before, the correlation between height and leaf area would be lessened as illustrated in Figure 1.

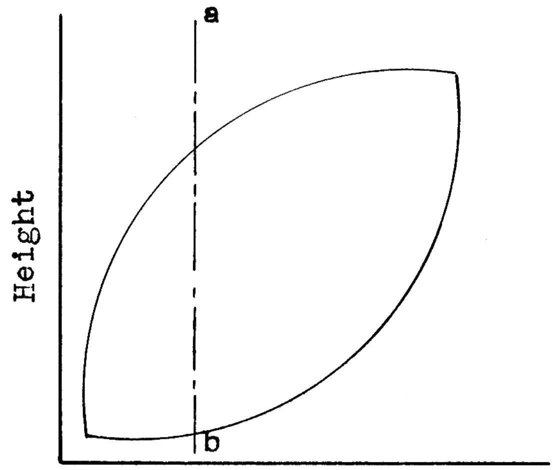



Figure 1

If the portion of the swarm to the left of line ab in Figure 1, representing the less leafy types, could be eliminated leaving only the portion of the swarm to the right, it can be seen that the correlation between leaf area and height will be less than in the whole swarm. This is essentially what has been attempted by selection in Andropogon scoparius and the correlation coefficients indicate a trend in this direction.

Further evidence that selection has brought about this decrease in correlation coefficient is the fact that the 1935 nursery (first generation) showed a correlation coefficient of .66±.03 in their first season of growth as compared to .56±.10 in their third generation. This indicates that in young plants the correlation between height and leaf area is higher than in older plants. However, in the selected generations the exact opposite of this has been observed, the young plants having a correlation of .31±.04 as compared with .43±.05 for their parents and .56±.10 for their grandparents, on the basis of data taken in 1937.

Leaf Area to Time of Maturity. In nature it has been observed that late plants, in general, tend to be more leafy than early ones. To show that such a relationship actually exists, heading dates of a number of plants of the 1935 nursery have been correlated with leaf areas, giving a coefficient of correlation of .25±.05. The method of obtaining heading date has already been discussed. These plants were in their third season of growth, hence were well stabilized. They were unselected and thus representative of the wild population. Considering these two facts, the correlation coefficient of .25±.05 bears out the observation that late plants are, in general, the leafy plants.

Selection of leafier and later plants have reduced the relationship existing between heading date and leafiness as shown by the correlation coefficient of .18 in the second generation and .003 in the third. As has already been stated, heading date has been made later and much more uniform by selection, while leaf area has, to a certain extent, been both increased and made more uniform. This tends to group the population so closely that the correlation is minimized.

# SUMMARY AND CONCLUSIONS

1. *Andropogon scoparius* in nature is an extremely variable species, divided into rather definite habitat types (the ecotypes of Turesson), which, however, exhibit considerable variability within themselves. In general, northern types are earlier, less leafy, and smaller than types from farther south.

2. Leaf area is the best single measure of quality and yield of forage. Wide variations in total leaf areas exist that are due to genetic differences in the plant. This is shown by the fact that the progeny of individual plants vary significantly from the progeny of other plants. The variability between these groups is greater than the variability within them. This indicates that selection, even in open-pollinated population, tends to increase uniformity.

3. No satisfactory measure of quality has yet been devised. Grazing tests are probably the best measure and shall be applied before final selection of strains is made.

4. Basal diameter of the plants varies widely, yet there is a tendency toward uniformity within groups of progeny of individual plants.

5. Plant height has not been an important factor in selection of superior types of plants, yet studies indicate it to be definitely influenced by genetic make-up. There

is a marked uniformity within the progeny of selected plants.

6. It is indicated that time of maturity can be changed by selection. This will make it possible to produce a strain that heads later, hence gives a longer summer grazing season. It is important that time of maturity be as late as possible, yet not so late that plants are frosted before producing seed.

7. Seed set is reduced by selfing in Andropogon scoparius. It is not definitely known whether this reduction in seed set is due to genetic causes or to abnormal conditions within the selfing bags.

8. There is no evidence to indicate that selfing has any effect on germination, for selfed seed has been found to have as high germination percentages as that from open-pollinated plants.

9. Differences have been observed in rate of germination. It is important that grasses should germinate quickly in order that the seedling plant become established before summer droughts. Seedlings that become established quickly are better able to compete with weeds and other grasses.

10. Rather definite relationships have been found to exist between certain characters in Andropogon scoparius, and that these relationships follow definite trends.

(a) Basal diameter is correlated positively with number of culms, with a tendency for the correlation to be higher in younger plants.

(b) Basal diameter is also correlated positively with plant height but no trends can be observed. Since these characters are expressions of general vigor, their high positive correlation is in accordance with expectations.

(c) Basal diameter and leaf area are positively correlated, the highest correlation existing in young plants.

(d) Height of plant and leaf area, while positively correlated, exhibit the highest correlation in older plants. Evidence indicates, however, that the low correlation in the third generation may be due to the effect of selection rather than to age of plants.

(e) In general, late plants tend to be leafier than early plants. After two generations of selection, however, no correlation exists between these two characters.

11. A limited amount of evidence on the effect of self-fertilization on general vigor is available. It indicates that the vigor of *Andropogon scoparius* is not seriously, if at all, affected by inbreeding.

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## LITERATURE CITED

(1) Albertson, F. W.
Ecology of the mixed prairie in west central Kansas. Ecological Monographs, 7:481-547. 1937.

(2) Aldous, A. E.
Bluestem pastures. In Kans. St. Bd. Agr. Bienn. Rept. 28:184-191. 1931-1934.

(3) __________
Pastures for western Kansas. In Kans. St. Bd. Agr. Bienn. Rept. 29:134-139. 1933-1934.

(4) __________
Kansas pasture grasses. In Beef Cattle in Kansas. Rept. Kans. St. Bd. Agr. 52(211B):155-170. 1934.

(5) __________
Economic value of native Kansas grasses. In Grasses in Kansas. Rept. Kans. St. Bd. Agr. 55(220A):13-23. 1936.

(6) Barker, H. D. and Hayes, H. K.
Rust resistance in timothy. Phytopath. 14:363-371. 1924.

(7) Beddows, A. R.
Seed setting and flowering in various grasses. Welsh Plant Breeding Sta. Bul. H. 12:5-99. 1931.

(8) Bruner, W. E.
The vegetation of Oklahoma. Ecological Monographs, 1:99-188. 1931.

(9) Calder, J. W.
Methods employed in the breeding of pasture plants. Imp. Bur. Plant Genetics (Aberystwyth) Bul. 11:63. 1933.

(10) Church, G. L.
Meiotic phenomena in certain Gramineae. II. Paniceae and Andropogoneae. Bot. Gaz. 88:63-84. 1929.

(11) Deam, C. C.
Grasses of Indiana. State of Indiana Dept. of Conservation Pub. No. 82. 356 p. 1929.

(12) Evans, M. W.
Selection of open-pollinated timothy. Jour. Amer. Soc. Agron. 28:389-394. 1936.

(13) ____________, Allred, H. A., and McConkey, O.
Time of heading and flowering of early, medium, and late timothy. Sci. Agr. 15:573-579. 1935.

(14) Gregor, J. W. and Sansome, F. W.
Experiments on the genetics of wild populations. I. Grasses. Jour. Gen. 17:349-364. 1927.

(15) Hayes, H. K. and Barker, H. D.
The effects of self-fertilization on timothy. Jour. Amer. Soc. Agron. 14:289-293. 1922.

(16) ____________ and Clarke, S. E.
Selection in selfed lines as a means of improving timothy. Sci. Agr. 5:313-317. 1925.

(17) Hilgendorf, F. W.
Plant breeding at Canterbury Agricultural College. Work on cereals, grasses, and red clover. N. Zeal. Jour. Agr. 36:156-171. 1928.

(18) Hitchcock, A. S.
Manual of grasses of the United States. U. S. Dept. Agr. Misc. Pub. 200. 1040 p. 1935.

(19) House, H. D.
Report of the New York State Botanist. N. Y. State Museum Bul. 243-244. 102 p. 1921.

(20) Hubbard, F. T.
Andropogon scoparius in the United States and Canada. Rhodora, 19:100-107. 1917.

(21) Hunter, A. W. S.
A karyosystematic investigation in the gramineae. Canad. Jour. Res. 11:213-241. 1924.

(22) Jenkin, T. J.
Self- and cross-fertilization in Lolium perenne. Jour. Gen. 17:11-17. 1926.

(23) ________
Self-fertility in rye grass. Welsh Plant Breeding Sta. (Aberystwyth) Bul. Ser. H. No. 12:100-119. 1931.

(24) ________
Method and technique of selection, breeding and strain building in grasses. Imp. Bur. Plant Genetics, Herb. Plants Bul. 3:3-34. 1931.

(25) ________
Natural selection in relation to the grasses. Roy. Soc. (London) Proc. Ser. B 121:52-56. 1936.

(26) ________
Some aspects of strain building in herbage grasses. Rept. 4th Internat'l Grassland Congress, Gr. Brit. 54-60. 1937.

(27) Keyser, A.
Variation studies in brome grass. Colo Agr. Expt. Sta. Bul. 190. 20 p. 1913.

(28) Kirk, L. E.
Self-fertilization in relation to forage crop improvement. Sci. Agr. 8:1-40. 1927.

(29) ________
Breeding improved varieties of forage crops. Jour. Amer. Soc. Agron. 19:225-239. 1927.

(30) Lewitsky, G. A.
The karyotype in systematics. Bul. Appl. Bot. 27:187-240. 1931. (Russian-English summary)

(31) Longley, A. E.
Chromosomes in grass sorghums. Jour. Agr. Res. 44:317-321. 1932.

(32) Malte, M. O.
Breeding methods in forage plants. Sci. Agr. 1:25-29. 1921.

(33) Nilsson, F.
Studies in fertility and inbreeding in some herbage grasses. Hereditas, 19:1-162. 1934.

(34) Nilsson-Leissner, G.
Preliminary inbreeding experiment in red fescue. Hereditas, 18:115-121. 1933.

(35) Sarvis, J. T.
The composition and density of the nation's vegetation in the vicinity of the Northern Great Plains Field Station. Jour. Agr. Res. 19:63-72. 1920.

(36) Săulescu, N.
Contributions to the breeding of grasses. Rept. 4th Internat'l Grassland Congress, Gr. Brit. 264-269. 1937.

(37) Schaffner, J. H.
The characteristic plants of a typical prairie. Ohio Nat. 13:65-69. 1913.

(38) Snedecor, G.
Analysis of variance. Ames, Iowa, Collegiate Press Inc. 96 p. 1934.

(39) Stapledon, R. G.
Characters which determine the economic value of grasses. I. Nutritive value and palatability. Jour. Min. Agr. (Gr. Brit.) 33:1083-1091. 1927.

(40) ________
The making of pasture. VI. The value and use of indigenous strains. Roy. Agr. Soc. England, 92:106-125. 1931.

(41) ________
The Welsh Plant Breeding Station. An account of its organization and work. Cambrian News (Aberystwyth) Ltd. 164 p. 1933.

(42) Steiger, T. L.
Structure of prairie vegetation. Ecol. 11:170-217. 1930.

(43) Sylven, N.
Importance of ecotype formation for the breeding of herbage plants. Rept. 4th Internat'l Grassland Congress, Gr. Brit. :40-45. 1937.

(44) Trumble, H. C.
Improvement of Phalaris spp. by selective breeding. Imp. Bur. Gen., Herb. Plants Bul. 7:17-20. 1932.

(45) Turesson, G.
The genotypical response of the plant species to the habitat. Hereditas, 3:211-350. 1922.

(46) ____________
The species and variety as ecological units. Hereditas, 3:100-113. 1922.

(47) U. S. Forest Service.
Range plant handbook. U. S. Gov. Printing Office, Washington, D. C. 1022 p. 1937.

(48) Valle, O.
The breeding of grassland plants. Rept. 4th Internat'l Grassland Congress, Gr. Brit. :252-258. 1937.

(49) Vinall, H. N. and Hein, M. A.
Breeding miscellaneous grasses. U. S. Dept. Agr. Yearbook of Agr. :1032-1107. 1937.

(50) Waldron, L. R.
Physical and chemical studies in brome clones and sibs. N. Dak. Agr. Expt. Sta. Bul. 152. 28 p. 1921.

(51) Weaver, J. E.
Underground plant development in relation to grazing. Ecol. 11:543-557. 1930.

(52) ____________ and Albertson, F. W.
Effects of the great drought on the prairies of Iowa, Nebraska, and Kansas. Ecol. 17:567-639. 1936.

(53) ____________ and Fitzpatrick, T. J.
Ecology and relative importance of the dominants of the tall grass prairie. Bot. Gaz. 93:113-150. 1932.

(54) ______________ and ________________
The prairie. Ecological Monographs, 4:109-295. 1934.

(55) Williams, R. D.
Heterosis in red clover. Effect of inbreeding in $F_2$ and $F_3$ populations. Welsh Jour. Agr. 13:172-190. 1937.

(56) ________________
Genetics of red clover and its bearing on practical breeding. Rept. 4th Internat'l Grassland Congress, Gr. Brit. :238-251. 1937.

(57) Wolfe, T. K. and Kipps, M. S.
Pollination studies with orchard grass. Jour. Amer. Soc. Agron. 17:748-752. 1925.