The Influence of Management Practices on The Growth Cycle of *Bromus inermis* Leyss. in Southern Manitoba

by

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ABSTRACT

Production, growth and development of bromegrass (Bromus inermis Leyss.) tillers on Red River clay fertilized in spring, midsummer or late fall with 185 lbs./acre of 27-14-0 and on non-fertilized areas were compared at frequent intervals under three harvesting systems. Seed yields in the range 200-670 lbs./acre were obtained. Seed production in 1964 equalled the combined production of 1965 and 1966. Differences in favour of fertilizer additions were not evident until the third harvest year.

Forage dry matter yields were higher from two cuts per year than from one cut and averaged 4.3 tons per acre in the most productive year, 1965. Application of fertilizer in spring produced the most equitable distribution of forage between spring and summer cuts, and the application of fertilizer in late fall produced the highest proportion of dry matter in the first cut. Fertilizer application increased total dry matter yields by 50%.

Forage protein yields were highest from two cuts per year. The first harvest year produced the highest protein yield of 1000 lbs./acre from fertilized areas and 650 lbs./acre from non-fertilized areas. Production dropped 10% to 20% per year in succeeding years. The second cut produced approximately half the protein of the first cut.

Deterioration of the bromegrass stand resulting in the "sodbound" condition was accompanied by reductions in density, height, and growth rate of tillers. Addition of fertilizer prevented or reduced the deterioration

of the stand. The time of year at which fertilizer was applied was not critical.

A temporary increase in growth rate was sometimes observed after the application of fertilizer in spring or summer.

Jointing in bromegrass started in early May, probably in response to suitable temperatures and stopped in late August when daylength became too short. During the jointing period, the rosette tiller was an evanescent stage between crown buds and jointed tillers. A harvest taken during this period removed all top growth and returned the growth cycle to the point at which it had started. For a period of 4 to 6 weeks after the start of growth or after a harvest, the number of crown buds was low. From late August to the cessation of growth in late fall, new tillers appeared continually from crown buds. The rosette tiller stage represented a considerable proportion of the tiller population. Cutting did not remove all top growth.

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INTRODUCTION

Smooth bromegrass (*Bromus inermis* Leyss) is the most extensively grown forage in Manitoba. Of the 1.7 million cultivated acres devoted to forage (2), perhaps seventy per cent consists of bromegrass, usually in a mixture with alfalfa. Pure stands of bromegrass are usually not grown, excepting a small acreage for seed production.

Research to date has concentrated on varietal testing and fertilizer studies of an empirical nature, to answer the questions posed by the farmer: which is the best variety of bromegrass for hay and/or pasture production, how much fertilizer should be put on, and what time of year is most suitable for application?

The answers obtained have not entirely solved the problems presented by the growth pattern of bromegrass. These problems are the vigorous growth competing too strongly with associated species followed by a "sodbound" state after about three years growth, and the inequality of high spring production and low summer production of forage. Work in the United States has indicated that poor growth in summer is the result of mismanagement through insufficient knowledge of the growth habits of the grass. Other research suggests that "sodbinding" can be alleviated by applying nitrogenous fertilizer.

Little is known about bromegrass tiller reaction to differences in the environment, apart from studies in photoperiodism in connection with seed production. The following study was undertaken to help fill the gap in knowledge of the growth and development of bromegrass under both forage and seed production conditions.

REVIEW OF LITERATURE

Smooth Bromegrass (*Bromus inermis* Leyss) is a perennial, cool season grass native to North and Central Europe and to temperate Asia (11, 73). The plant has stout stems from one to four feet high, with lax, spreading leaves and a loose panicle type of inflorescence. Vegetative propagation is by rhizomes which spread to produce, initially, a loose mat and later a dense turf which often becomes "sodbound".

Several introductions have been made into North America. The first on record was in 1884 when the California Experimental Station of the United States Department of Agriculture received seed, probably from Hungary. Shortly after this, seed was imported to Canada from Germany (11). Later introductions to both Canada and the United States came from Russia (73).

The diversity of these introductions, and of the selections made from them has led to the recognition of two fairly distinct types of smooth Bromegrass: the Northern type, derived from North German and Russian sources and adapted to the climate of Canada and the northern United States; and the Southern type, originating mainly from the Hungarian source and adapted to the central part of the United States. The differences between the two types are of degree rather than of kind: plants of intermediate type have been observed. Newer varieties contain genetic material from both Southern and Northern sources (27, 32, 59).

For forage production, varieties of Southern type are superior in the mid-western United States (5, 74) probably because of their higher optimum growth temperature (20). This superiority is not so absolute in more northerly areas. In Manitoba, Southern types have given higher yields in the past (68), but new varieties of Northern or intermediate genotype now under test appear to produce forage yields equal to or better than the currently recommended Southern variety "Lincoln" (61, 62). Knowles and White (34) found no differences in yield between the two types when grown at several locations in Western Canada. In Michigan, Churchill (10) found that Southern varieties were best; on the other hand, Tesar and Sheperd (65) observed that Northern varieties were better on peat soils. Northern varieties produce higher seed yields than Southern types (59, 61).

The extensive use of bromegrass throughout the central and northern prairie regions of North America has led to considerable research into the production of forage and seed from it. Empirical experimentation with methods of seeding, and rates and times of fertilizer applications has led to some conclusions for seed production. These are that nitrogenous fertilizers will generally increase seed yields (6, 7, 33, 53, 55, 59, 61, 62), that higher yields are produced by brome grown in rows rather than in solid stands (7, 53), that fertilizer applied in late summer or autumn produces the greatest seed yield increase (12, 19, 33, 53) and that the most economic rate of fertilizer application may not be the one which produces the greatest yield (33, 53).

Investigations into the use of bromegrass for pasture and hay production are harder to assess. The almost infinite permutations that rate and time of application and chemical composition of fertilizer can make with cutting date, height and frequency over the wide range of climatic conditions found where brome is grown, have led to experiments which, while possibly answering the immediate problems posed, have produced little information specific to bromegrass. A sampling of the published results reveals that bromegrass, in common with other cool season grasses will consistently give an increase in dry matter yield (9, 14, 21, 24, 33, 41, 43, 51, 55, 58, 71, 75) and crude protein percentage (8, 13, 21, 44, 66) when nitrogenous fertilizers are applied. Pure stands of bromegrass that have become "sodbound" can be rejuvenated by judicious applications of nitrogen (6, 13, 66). The increased vigor and yield resulting from nitrogen applications of as high as 200 pounds per acre have shown a positive linear relationship with rainfall (13, 66) in low rainfall areas. Increased production has not always been economic (14, 21, 33, 66). Responses to the application of other macro elements have been inconsistent (12, 59, 66). This is probably because they are not so frequently inadequate for normal growth.

For forage purposes, the use of pure brome stands has been superseded by a brome-alfalfa mixture in the drier localities and by a mixture of brome and ladino or red clover in higher rainfall areas. The factors most frequently influencing this replacement are that a higher forage yield is obtained from the mixture than from grass grown alone (10, 26, 40, 44, 47, 57, 59, 61, 62, 68, 71), a more even growth throughout the growing season is maintained (3, 10, 75), the legume can supply in part or in total the nitrogen necessary for continued satisfactory grass production (9, 58, 71, 75), and a mixture of two (or more) widely differing species growing together insures against crop failure should conditions become unfavorable for one of the species (3, 58, 74).

The use of legumes in brome stands has added the problem of competition to the complexities of brome production studies. Some workers have found that bromegrass will increase at the expense of the legume when the two are grown together (26, 47, 71). The converse view has also been stated, namely that brome decreases as the stand ages (31, 58, 68). However, the majority of the results indicate that management treatments, and in particular the cutting treatments imposed, control the balance between brome and legume (12, 14, 28, 29, 30, 66, 75) and indeed, whether the bromegrass will survive at all (31, 56, 75).

The evidence presented above is but a sample of the considerable quantity of data which is available concerning the overall effects of fertilizer and cutting practises on brome grown alone or with a legume. Among it there is little evidence to indicate how the visible effects on production are brought about. If maximum production is to be obtained from bromegrass, it is essential to know how the treatments applied effect the changes appearing as yield differences. For this, it is necessary to study the effects of growing conditions on the growth and development of the brome plant.

The work of Gregory and Purvis, Cooper, Mitchell and others, on a number of grasses has revealed some of the complexities of tiller production and development: in particular that grass species differ in their responses to similar conditions (16, 37, 38, 39, 49, 54). Work of a similar kind on bromegrass is much less extensive. Most of the work has been into investigating inflorescence initiation and development. Some disagreement has arisen over the precise combination of short days and low temperatures necessary to initiate flowering in brome. Allard and Evans (1) found that short day treatment alone produced no flowering shoots. Gall (25) also observed that chilling was necessary in most cases, with the exception of a Manchurian clone which he found would flower without a cold period. Newell (51) stated that the clones with which he worked required a period of growth under short day and cool temperature conditions. A consensus of opinion might be that a period of short days is required together with cool but not necessarily freezing temperatures (17). It is possible that the variation observed has been due to genetic differences in the material, as is the case in Lolium species (15, 16) and some range grasses (52). Once floral initiation has taken place, all workers agree that long days are best for internode elongation and flower excision (1, 24, 25, 51).

In timothy and meadow fescue, not all tillers present during a period of treatment favourable to flower initiation will develop inflorescences (37,38). Bromegrass appears to behave similarly (24, 36). Waldron (69) has ascribed clonal variation of the ratio of fertile to sterile tillers produced by brome in spring to gene differences. However, Lamp (36) observed in spaced plants that more fertile tillers compared to sterile tillers emerged at the edges of his clones than in the centres, because, he suggested, of more favourable growing conditions.

The sterile tillers produced concurrently with and after the fertile tillers appear to be important for the perennial habit, at least in timothy (37), where tillers rarely survived more than one year irrespective of the time of their initiation. From available descriptions of other grasses including bromegrass, it appears that they too depend on successive cycles of tiller production throughout the growing season for their perennial habit. These tillers in a suitable stage of development at the end of the growing season become dormant and remain so until growing conditions again become favourable (36, 37, 38).

In bromegrass, tillers can be identified with one of the following stages of development (36): crown buds and rhizomes, tillers with green leaves in a rosette enclosing a growing point which is at or slightly below ground level, and tillers in which the growing point has become elongating internodes. The two latter stages of growth can be found with either vegetative or fertile shoot apices.

Lamp (36) found that the development of new tillers in brome clones proceeded from the crown bud to the rosette stage at which floral initiation might or might not take place depending on temperature and daylength conditions, genetic factors, and the level of fertility of the soil as mentioned above. In either case, subsequent growth resulted in the growing points being raised above ground level. Eventually the tillers either died or were harvested.

At the latitude of Chicago (36), bromegrass tillers which survived the winter were in either the crown bud or the rosette stage of development. Growth started from the rosettes in mid-March and more tillers emerged from the ground shortly afterward. Lamp suggested that the emerging tillers had also initiated growth the previous fall but had had their development stopped by cold weather.

Growing point dissection revealed discernible inflorescence development by mid-April and growing points continued to develop into flower primordia until internode elongation started in early May. A second period of new tiller emergence commenced at anthesis in early June and continued until growth was arrested by cold weather in late fall. More new tillers were produced in late summer and fall than in spring. During internode elongation in spring, only a few new tillers emerged. Later observations by Teel (64) have substantiated this finding, and Langer (39) has reported similar variations in tillering in solid stands of timothy and meadow fescue.

From leaf counts during the year, Lamp (36) concluded that a minimal number of leaves was required before a tiller would respond to vernalisation. He further suggested that tillers developing the minimum number of leaves before internode elongation started would flower; otherwise they would remain sterile even though they produced enough leaves to surpass the minimum number. However, the variability of his minimum number (5 to 14 leaves per tiller) suggests that leaf number is but one of several factors which interact to control tiller readiness for vernalisation (25) by their effect on the nutrient status of the tiller.

Nutrient status is a difficult factor to measure. Many workers have equated it with soluble carbohydrate reserve levels in rhizomes and stem bases (22, 45, 46, 60, 72). They have found that the soluble carbohydrate content of bromegrass rhizomes decreases in spring during initial growth, and decreases after cutting or grazing a stand. Reduction of soluble carbohydrate levels to near zero has coincided with death of the plants (63) and high levels have occurred at the ends of periods of uninterrupted growth (59). Whilst it has been demonstrated that nitrogenous fertilizer can increase tiller numbers and accelerate leaf production (70), it has also been stated that fertilizer cannot replace carbohydrate reserves (72). If a stand is cut frequently, recovery growth is soon reduced to a very low level, in spite of a high soil fertility. Presumably, carbohydrate reserves have been reduced after each cutting and insufficient time has been allowed for their replenishment.

This review has attempted to summarise current knowledge of bromegrass behaviour. There is an obvious imbalance in knowledge between the well covered field of treatment effects on agricultural yield and the barely entered area of tiller population studies. In particular, little is known about bromegrass growth in terms of tiller reaction to changes in environment, apart from studies in photoperiodism from the viewpoint of flower and seed production.

MATERIALS AND METHODS

The bromegrass variety "Lincoln", a typical Southern type, is recommended to farmers by the Manitoba Department of Agriculture for its excellent forage production and good disease resistance. Seed of "Lincoln" is also produced to some extent, mainly for export to the U.S.A. where it is grown extensively for forage. The use of "Lincoln" for forage production in Manitoba and the probably future production of seed of this variety or of a similar Southern type for export made "Lincoln" the varietal choice for this project.

The experimental area was established on Red River clay in the experimental field of the University of Manitoba Plant Science Department. The area was subdivided according to a split plot design of four replications with four main plot treatments and three subplot treatments, giving a total of 48 subplots each 25 x 6 feet. On May 16, 1963, "Lincoln" bromegrass was drilled along the length of the subplots, in rows nine inches apart, at a seeding rate of ten pounds per acre. A marker row of Russian Wild Ryegrass was sown between each of the subplots and around each replicate.

The fertilizer treatments described below were assigned to the main plots.

(1) No fertilizer treatment, as a control.

(2) 185 lbs./acre 27-14-0, applied in the spring of each year.

(3) 185 lbs./acre 27-14-0, applied in the summer of each year.

(4) 185 lbs./acre 27-14-0, applied just before the ground froze in late fall.

Each fertilizer application contained 50 pounds Nitrogen and 26 pounds Phosphoric acid. The dates of fertilizer application are given in Table 1.

In the establishment year, annual weeds (mainly Barnyard Grass, Echinochloa crus-galli) posed a considerable problem. A combination of hoeing, hand weeding, and close mowing was used for their control. For this reason, no results were obtained until late 1963.

The following cutting regimes were applied at the subplot level in 1964, 1965, and 1966:-

(1) The grass was allowed to grow to maturity and was harvested for seed.

(2) The grass was harvested at full bloom, a stage of development considered suitable for hay production.

(3) The grass was cut twice during the growing season; once in early summer at the time of inflorescence emergence from the sheath, and once in early fall when growth had almost finished for the season. This treatment approximated to the management suggested by agronomists for pasture use in the province.

Data was obtained in 1964, 1965 and 1966 by harvesting an area 20 x 3 feet from each subplot in each replication. Estimations of forage production as green weight, dry weight and crude protein from one cut and two cuts per year, and of seed yield and thousand kernel weight were made for the four fertilizer treatments described above. After the material had been removed, the remaining area of each subplot

Table 1

Dates of fertilizer application to bromegrass plots

Year	Spring	Midsummer	Fall
1963	16/5	26/8	2/11
1964	20/5	14/8	11/11
1965	9/5	13/8	19/4/66#
1966	3/6	28/7	-

Snowfall prevented fall application

Table 2

Seed and forage harvest dates

Year	Seed harvest	Single cut	Double cut	
			First	Second
1963		No harvest		
1964	30/7	7/7	5/6	13/8
1965	4/8	9/7	21/6	20/9
1966	25/7	25/7	28/6	5/10

Table 3

Dates of bromegrass tiller sampling

1963	1964	1965	1966
2/11	28/5	18/5	11/5
	18/6	6/6	7/6
	8/7	4/7	7/7
	5/8	27/7	16/8
	28/8	25/8	15/9
	18/9	18/9	31/10
	14/10	15/10	
	11/11		

was cut and the stubble was trimmed to a height of three inches with a rotary mower. Harvest dates for the three years are given in Table 2.

Samples of fifty tillers were dug from each subplot in the late fall of 1963 and at intervals during the growing seasons of 1964, 1965 and 1966 (Table 3). The tillers were chosen as a group by random selection of a location not immediately adjacent to spaces left by previous sampling or to the edge of the subplot but within the part of each subplot which was not used for estimating yield data. This avoided the introduction of bias into the yield data. The tillers were washed free of soil and stored at -10° C until they were dissected.

At the time of dissection, quantitative data was recorded on the following characters:-

(1) Height.
(2) Number of exserted laminate leaves.
(3) Leaf initials around the growing point.
(4) Number of extended internodes.
(5) The production of leaf or flower primordia by the growing point.
(6) Any visible factors affecting the health of the tiller.
(7) Height of the growing point above soil level (1965 and 1966 only).
(8) Stage of tiller development.

Each tiller was classified into one of five growth stages according to the development of its various parts. Tillers less than two inches long with no green leaves were classified as crown buds. Tillers more than two inches long, or with green leaves were separated into four types on the basis of the growing point being either at soil

Figure 1

Diagrammatic representations of the crown bud and rosette tiller growth stages in bromegrass

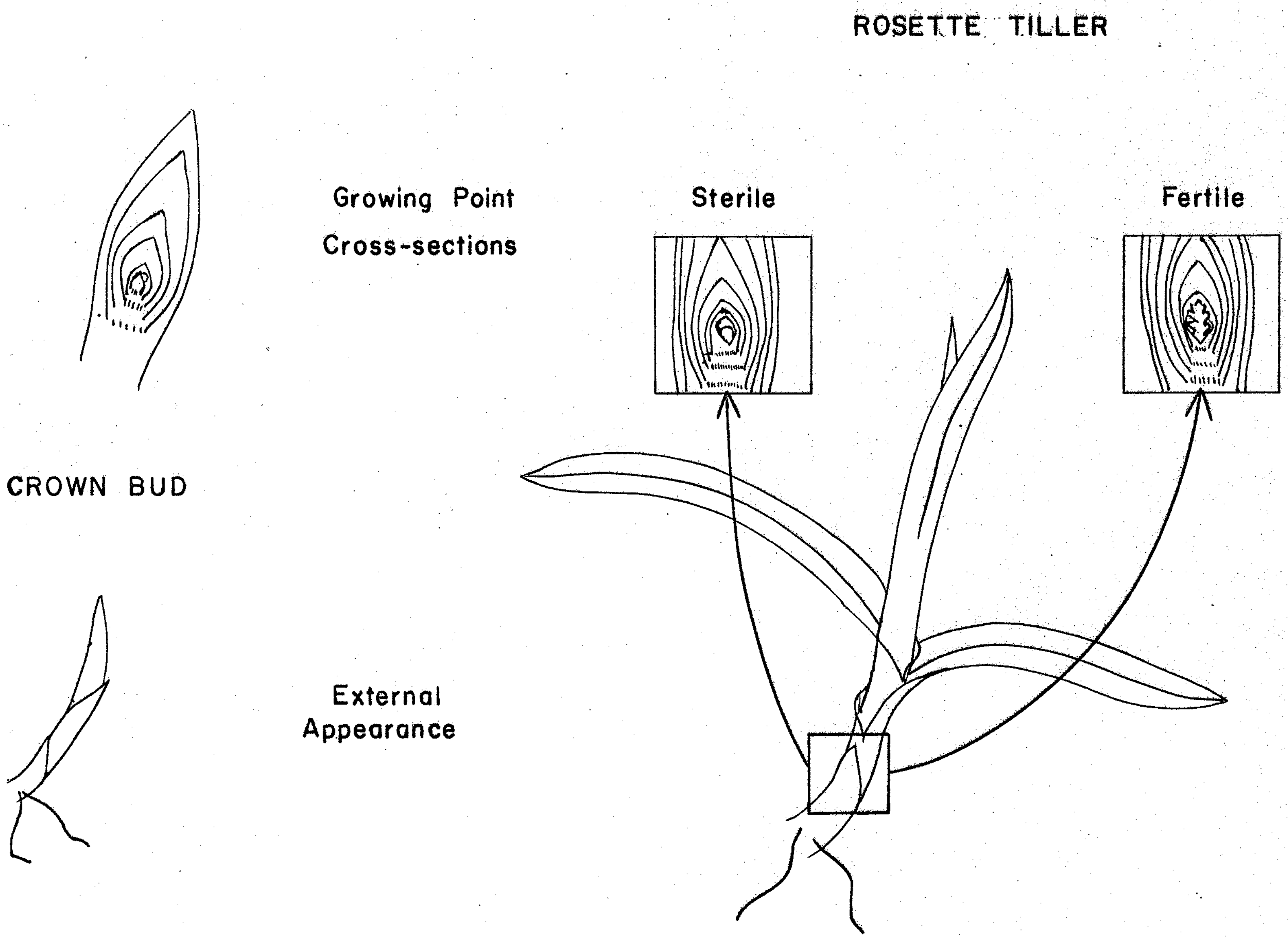
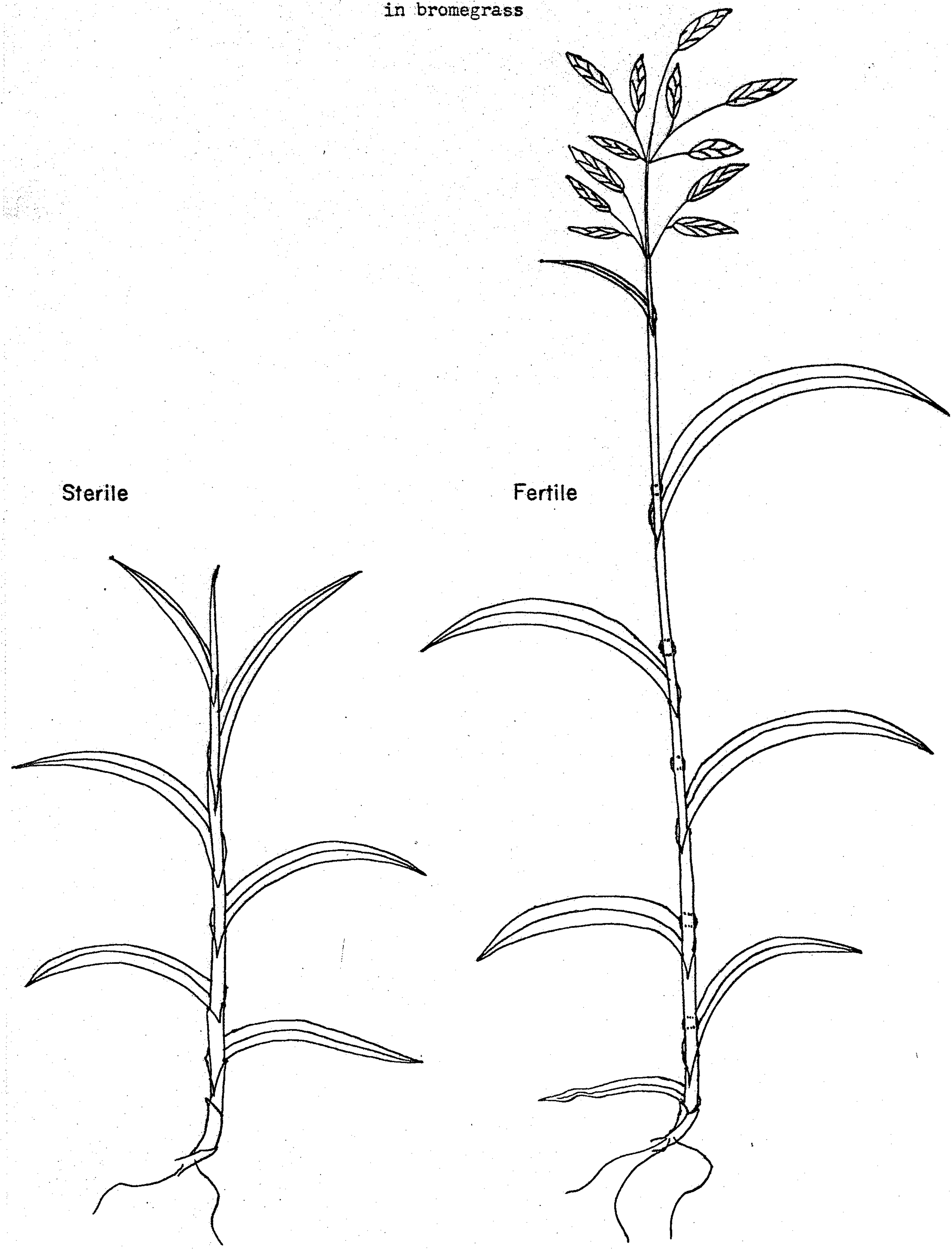
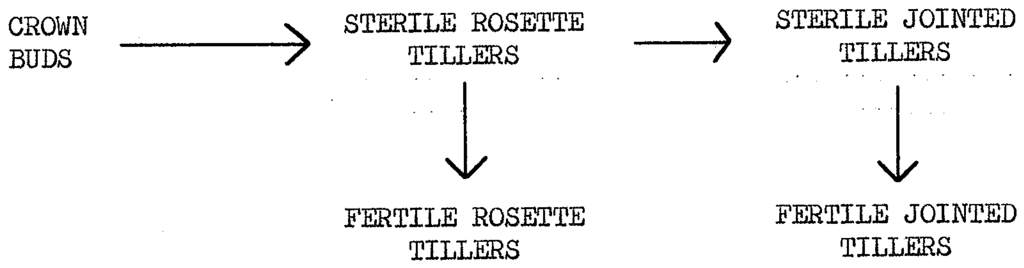


Figure 2
Diagrammatic representations of the jointed tiller growth stages in bromegrass



level or on an extended stem, and either producing leaf primordia only or having reached the flowering stage. Figures 1 and 2 show the salient features of the five tiller types.

The suggested (36) interrelationship between the five growth stages is presented below:-



For the purpose of this analysis, a tiller was defined arbitrarily as any bud or shoot longer than a quarter of an inch having a living, or apparently living growing point.

After dissection, the tillers were separated into roots, rhizomes, stems and leaves, and dried at 180 degrees Farenheit for 24 hours. The separated plant parts were weighed when dry and ground to pass a 40 mesh sieve using a micro Wiley mill. Analyses for crude protein content were made on the ground samples using the micro Kjeldahl technique (4).

Carbohydrate content of the rhizomes was estimated using the technique of Coukell (18) as modified by LaCroix (35).

Soluble carbohydrate content of the rhizomes was extracted by reflux digestion over a boiling water bath for 45 minutes, of a mixture of 100 milligrams of dried, ground rhizome, and 15 millilitres 0.02 N sulphuric acid. After filtering, and neutralizing with sodium hydroxide, the resultant solution was made up to 50 millilitres. To extract the insoluble carbohydrate from the rhizomes, the solid residue including the filter paper was subjected to reflux hydrolysis over a boiling water bath with 25 millilitres of 2.25 N. sulphuric acid for 2½ hours. The resulting solution was filtered, neutralized with sodium hydroxide and made up to 250 millilitres.

To estimate the sugar content of the solutions, 2 millilitres of the solution was mixed with 2 millilitres of dinitrosalycilate reagent (Appendix 1) and heated in boiling water for five minutes. After cooling in ice water, 20 millilitres of water was added. The optical density was read on a colorimeter at a wavelength of 505 microns against a blank made by replacing the unknown sugar solution with 2 millilitres of water. Sugar content was calculated as maltose from a standard graph (Appendix 2).

To compare the effects of the different fertilizer treatments, separate statistical analyses were made for forage production under treatments of one cut and two cuts per year on the bases of both dry matter production and protein yield per plot considered over the three season experimental period. Additional analyses were made on the yearly plot production to compare the effects of the different seasons on forage production. Similar analyses were made on seed yields and thousand kernel weights.

The quantitative data obtained from tiller dissection were reduced to mean values and ranges per tiller stage for each treatment combination and are presented graphically.

RESULTS AND DISCUSSION

The results and discussion are presented in two sections: one devoted to bromegrass grown for seed production, and the other to growth for forage.

The illustrations presented have several features in common. These are:-

(1) A horizontal axis representing the late fall of 1963 and the three complete growing seasons of 1964, 1965 and 1966.

(2) Vertical broken lines representing the harvest dates.

(3) Vertical solid lines representing ranges of values obtained.

(4) Mean values marked "X" where growth discontinuities occur and joined by solid lines where growth between sampling dates was uninterrupted.

A. Seed Production

Seed yields obtained from the experimental plots in the years 1964 to 1966 are presented in Table 4. In 1964 and 1965 respectively, the non-fertilized plots produced 673 pounds and 300 pounds of seed per acre, compared to 527 pounds and 192 pounds per acre for the plots receiving 50 pounds of nitrogen per acre in the fall. In 1966, the non-fertilized plots produced 268 pounds of seed per acre compared with 416 pounds per acre from the plots fertilized in the fall. The same rate of fertilizer applied in spring or midsummer produced seed yields intermediate between these extremes in all years.

Statistical analyses of the data by years (Appendix 3) indicates that significant differences ($p<0.01$) between treatments were detected only in 1966 and only between fall fertilized and check plots.

The three year average seed production was slightly higher for the non-fertilized than for the fertilized plots. Statistical analyses (Appendix 4) showed that differences in yearly seed yield were significant ($p<0.01$). When averaged across all treatments, the quantity of seed produced in 1964was 605 pounds per acre and equalled the combined yields of 1965 and 1966. Such favourable conditions as high soil fertility, good moisture conditions, and a relatively thin stand of bromegrass in the fall of 1963 and the spring of 1964 permitted strong vigorous tillers to develop and these produced large panicles and a large seed crop. The fall of 1964 was relatively dry, and this could have adversely affected seed production in 1965.

Experiments both in Manitoba (61, 62) and in other parts of North America (6, 7, 33, 53, 55) have shown that nitrogenous fertilizers generally increase bromegrass seed production, particularly if the fertilizers are applied in autumn. Similar, though not significant ($p>0.05$) trends were noted in the third harvest year only. That no response was obtained in the present experiment was probably due to a high initial soil fertility level in the experimental area.

The thousand kernel weight (Table 5) ranged from 3.03 grams to 3.48 grams with little consistency among treatments. The non-fertilized areas produced heavier ($p<0.05$) seed in 1964 and 1965. In 1966, the plots receiving a spring application of fertilizer produced significantly ($p<0.05$) heavier seed than all other plots (Appendix 5). This may have been due to the relatively late date of application of fertilizer that spring.

Significantly ($p<0.01$) lighter seeds were produced in 1966 than in 1965 and 1964 (Table 5, Appendix 6). Seeds produced in 1966 averaged 3.16 grams per thousand compared to 3.38 grams in 1964 and 3.42 grams in 1965. The lighter seed in 1966 was characteristic of all plots except those fertilized in the spring, where seed weight was the same as in 1965 (Table 5).

The pattern of tiller development under management for seed production is shown graphically in Figures 3 to 13 and in Appendices 7 to 10. By the end of the establishment year, the experimental

Table 4

Seed yields of "Lincoln" bromegrass as influenced by fertilizer applications at Winnipeg

Time of fertilizer application	Yield by harvest year (lbs/acre)			Three year average yield
	1964	1965	1966	
None applied	673.0[#]	300.2	268.5	413.9
Spring	625.0	260.8	343.4	409.7
Midsummer	597.5	261.9	327.2	395.5
Late Fall	527.1	191.9	415.9	378.3
Yearly average	605.6	253.7	338.8	

[#] Yields are the average of four replicates

Table 5

Thousand kernel weight (grams) of "Lincoln" bromegrass as influenced by fertilizer applications at Winnipeg

Time of fertilizer application	Harvest year			Treatment average
	1964	1965	1966	
None applied	3.48 #	3.48	3.12	3.36
Spring	3.30	3.42	3.41	3.38
Midsummer	3.35	3.44	3.03	3.27
Late Fall	3.39	3.34	3.08	3.27
Yearly average	3.38	3.42	3.16	

Values are the average of four replicates

plots contained brome tillers at all five of the stages of growth outlined above, although fertile tillers made up only 4% of the population. Tillers with one or more green leaves surrounding a soil level growing point (hereafter called sterile rosettes) made up 60% of the tiller population, another 16% were sterile tillers with elongated internodes (sterile jointing tillers) and the remaining 20% were crown buds (Figures 3, 4, 5, 6). There were no differences attributable to fertilizer applications the spring or summer of the establishment year.

The length of the crown buds averaged 0.8 inches and ranged from 0.25 to 2.0 inches (Appendix 7). The average height of the sterile rosettes was 4.5 inches and ranged up to 18 inches (Figure 7), while the number of green leaves ranged to 10 with an average of 2.7 leaves per tiller (Figure 10). The height of the sterile jointing tillers averaged 15 inches. Leaf production ranged from 4 to 24 leaves per tiller and increased in the manner:- Plots not receiving fertilizer $<$ plots with fertilizer applied in spring $<$ plots with fertilizer applied in summer. The latter treatment produced by far the greatest range of leaf numbers (Figure 11). The preponderance of the three sterile tiller classes in the population in the fall of 1963 indicates that they represented the main growth and development pathway after the initial seedling establishment in the spring.

The overlap in the ranges of height and green leaf numbers between the three tiller groups suggests that the initiation of crown buds and their further development was a continuous process, all stages of which were stopped by the onset of cold weather. Presumably the jointed tillers were the oldest part of the population, as bromegrass requires 15 to 16 hours daylength for internode elongation (24) and days of this length do not occur at Winnipeg after the twentieth of August (67).

Growth in the three subsequent years followed essentially a similar pattern each year. Above ground growth present in the fall was killed during the winter. This affected the sterile jointing tillers most, only an occasional survivor was found in the spring. Regrowth commenced in April from the sterile rosettes and crown buds which had survived the winter. Jointing started during the second week of May (Figures 3, 4, 5, 6). In 1966 in the sample taken on the 11th of May, 44% of the tillers had inflorescence primordia. The next sample, taken on the 6th of June showed no further increase in fertile tillers. It was concluded that inflorescence primordia production was complete by mid-May.

Stem elongation continued until mid-July by which time, the fertile tillers averaged 3.5 feet in height, with a range from 2.0 to 4.5 feet. The sterile jointed tillers consistently averaged half the height of the fertile tillers with a range from 0.5 to 3.0 feet. The numbers of leaves produced by a fertile tiller ranged from 5 to 16 (Figure 12) though only a few tillers had more than 13 leaves. On the average, 9 to 10 leaves were produced of which quite consistently 6 or 7 were elevated by the elongating stem (Appendix 10). The leaves were exserted in rapid succession in early spring and were followed by the flowering head in mid-June (Appendix 8). The range of leaf numbers found on sterile jointed tillers was from 2 to 19 leaves (Figure 11). The sterile tillers produced leaves more slowly but continued to exsert leaves after the fertile tillers had produced flowering heads. They also continued to expand new leaves after mid-July when stem elongation slowed down (Figure 11). As a result, by seed harvest time in late July or early August, the average sterile tiller had 11 leaves. However, the average number of leaf initials remaining round the stem apex decreased steadily from 6 to 3 during the period of spring growth suggesting that there is an upper limit to leaf production by a tiller under field conditions.

During the spring growth period, the proportion of rosette tillers decreased from 80% to near zero and remained at this level until after the seed harvest. The rosette tillers consisted of approximately equal numbers of fertile and sterile forms at the start of internode elongation. The number of fertile rosette tillers decreased most rapidly as they gave rise to fertile jointed tillers. By the end of May, less than 1% of the fertile rosette tillers had not elongated at least one internode, whilst 5% of the sterile tiller population consisted of rosette tillers. There was also an indication that the proportion of sterile rosette tillers in the population present at seed harvest time decreased as the stand aged (Figures 3, 4, 5, 6).

The proportion of crown buds in the population increased steadily during spring and early summer until, by the end of July, about half of the tiller population consisted of crown buds (Figures 3, 4, 5, 6). This is in apparent contrast to the results of Lamp (36) and Eastin et al (22) who found that few crown buds appeared during the jointing phase of growth. However, their observations were made on tillers appearing above ground level. Since most crown buds were less than half an inch long and remained below ground level until after the seed harvest, it is probable that the differences in crown bud growth between the present observations and those of the two reports cited above are due entirely to the different methods of data collection employed.

During the spring flush of growth, the dry weight of the fifty tiller samples increased considerably between sampling dates. Stem dry weight increased from zero to ten grams in the period covered by May and June. In the same period, the amount of leaf material increased from 5 grams to 15 grams dry weight. From the end of June to harvest, there was a decrease, probably caused by an excess of leaf death over production and the continued increase in crown buds which contributed nothing to leaf material.

During the spring growth period, protein levels declined. Stem protein at the start of jointing was equal to leaf protein at 18% of the dry weight. The subsequent rapid stem increase occurred concurrently with an equally rapid stem protein decrease to 2% at harvest. Leaf protein levels decreased less rapidly and levelled off at 8% to 10% in mid-June. Carbohydrate levels in the bromegrass rhizomes showed a decline during spring from 20% to 15% (Figure 13).

The seed harvest removed most of the photosynthetic material. Regrowth from the crown buds produced green leaves within a week (Figures 3, 4, 5, 6, 10) and some internode elongation took place by the end of August. From then until growth stopped at the end of October, the number of crown buds in the population increased from 20% to 35% or more with considerable variation between years and treatments, while sterile rosette tillers decreased in numbers from over 50% to 25% of the population (Figures 3, 4, 5, 6). Each year the tiller characteristics height (Figures 7, 8, 9), leaf numbers (Figures 10, 11, 12), and dry weight of leaf tissue, showed only small changes from mid-September to the end of the growing season. The ranges of the plant characteristics measured overlapped and large changes in the proportions of tiller types in the population produced only small changes in the characteristics measured.

Acid soluble carbohydrates in the rhizomes showed a marked increase from 20% to 35% during September and October (Figure 13), while leaf protein showed a decrease of 4%, probably to some extent because of increasingly severe frost damage as the growing season came to a close.

The pattern of tiller development described above agrees closely with the description of the growth of bromegrass at Chicago (36).

Differences in the time of appearance of growth stages during the season, can be ascribed to the combination of shorter growing season and longer daylength at Winnipeg. At Chicago, spring growth started about four weeks earlier and internode elongation was two weeks earlier than at Winnipeg (36). On the other hand, some jointing occurred at the Winnipeg location in mid-August, whereas Lamp (36) found no jointing after mid-July. On this point, there are some conflicts in the literature, Teel (64) stating that at Lafayette "jointing in midsummer is not infrequent". According to Evans and Wilsie (24) and Gall (25) bromegrass requires 15 to 16 hours of daylength for satisfactory stem elongation. At Winnipeg days of this length start in mid-April and end in late August. At Chicago, days of 15 to 16 hours daylight start at the end of April and end early in August (67). It is suggested that the start of jointing in spring at Chicago is controlled by daylength, and at Winnipeg by temperature, a similar situation to the one found in timothy by Evans (23). The cessation of jointing in summer in relation to the reduction of daylength below 15 hours is less clear. The evidence presented by Lamp (36) and Teel (64) is conflicting, but suggests that little internode elongation occurs after the end of July, the approximate time of year when daylength falls below 15 hours in the localities of Chicago and Lafayette. In Winnipeg, jointing was observed to take place in some tillers until late in August, again corresponding to the time at which daylength falls below the critical period. Undoubtedly much of the inexactitude of the end of jointing observations compared to the start of jointing lies in the relative difficulty of deciding when an internode stops elongating as opposed to the ease of observing when it starts.

Imposed on the general growth pattern described above were effects which, it is suggested, were caused by the fertilizer treatments applied, by year to year meteorological differences, by the age of the grass stand, and by interactions among these three factors.

Of the three years for which results were obtained, 1964 data showed marked differences from those obtained in the two subsequent years. The proportion of fertile tillers in the population in the spring of 1964 showed a considerable drop from 60% in late May to 35% in early July. The proportions in 1965 and 1966 were relatively constant at values of 20% and 35% respectively over the spring growth period. There appeared to be no differences due to fertilizer treatments (Figures 3, 4, 5, 6).

In all years, the proportion of crown buds increased after mid-May, but only in 1965 was the increase similar between the various fertilizer treatments, increasing from 5% to 10% in mid-May to 45% by the end of July. The plots receiving fertilizer in spring produced crown buds more rapidly in June than the other treatments. In 1964, an increase of crown buds in all plots in early June was followed by a decrease in the plots fertilized in spring and late fall. By the end of July, non-fertilized and summer fertilized plots had 50% of their tillers as crown buds whereas the other plots had only 35% crown buds. In 1966, the proportions of crown buds in the populations by harvest time were the exact reverse of the 1964 proportions, being 50% for the plots fertilized in spring and fall, and 35% for the others. Especially notable was the rapid increase to 35% of crown buds in the non-fertilized plots in May. The fertilized areas had only 20% crown buds at the end of May and increased most rapidly during June (Figures 3, 4, 5, 6).

Fertilizer appeared to have no effect on the frequency of sterile rosette tillers in the population. Under all treatments in 1965 and 1966, the number of sterile rosette tillers was high in early May and fell to less than 2% by the end of July. In 1964, there was a resurgence of these tillers from a low of almost zero at the end of May to 10% in early July (Figures 3, 4, 5, 6).

Fertilizer also had no effect on fertile rosette tiller frequency. They decreased in number from 40% in early May to zero by the beginning of June (Figures 3, 4, 5, 6).

The sterile jointing tillers were not consistent in behaviour. In 1964, all treatment areas had only 10% sterile jointing tillers at the end of May. The non-fertilized and summer fertilized areas remained at this proportion until the seed harvest was taken. Areas receiving fertilizer in late fall or spring showed a rapid increase of sterile jointing tillers after mid-June, and 25% of the tiller population was of this type at harvest time. In 1965 and 1966, the numbers of sterile jointing tillers increased from the start of jointing in early May to 50% by early June. Their numbers then decreased to 25% by the end of July. A fertilizer effect was evident in 1966; non-fertilized areas produced jointed tillers more slowly and had only 20% at the beginning of June. A similar but less distinct effect was present in 1965. The areas fertilized in late fall also behaved differently from the general pattern in 1965, producing sterile jointed tillers more rapidly in the early spring than other treatments (Figures 3, 4, 5, 6).

It is clear that fertilizer treatments, irrespective of the time of application, had little effect on the proportions of the tiller population occupied by the five tiller types during the spring growth period in the areas devoted to seed production. There was some evidence of a higher fertile/sterile tiller ratio in 1966 in the areas fertilized in fall (Figures 3, 4, 5, 6). As the seed yield from the fall fertilized areas was superior only to that from the non-fertilized areas, it is doubtful if this fertile/sterile ratio difference is of significance. Of greater interest is the cause of the very large seed yields of 1964 compared to the low yields of 1965 and the moderate production of 1966. There was little difference in the fertile/sterile tiller ratios of 2:1 to 3:1 in 1964 and 1966, although seed yield differences between the two years were large (Table 4). In 1965, the ratio was 1:15 in favour of the sterile tillers, and seed yields were low. The evidence suggests that the relationship between fertile/sterile tiller ratio and seed yields is not close. More probably, seed production is affected by factors acting directly by influencing fertile tiller size, and indirectly via the fertile/sterile tiller ratio.

The fall of 1964 was dry between the end of August and November, whereas the same periods in 1963 and 1965 provided much better soil moisture conditions (Appendix 29). Also, in the fall of 1963, the bromegrass tillers in the experimental area were much less crowded than in subsequent years, because of insufficient time for new tillers to fill the spaces between the drill rows of the original seeding. Clearly, the tillers enjoyed very favourable fertility conditions in the fall of 1963 and early spring of 1964. Lamp (36), working with spaced clones, observed higher fertile/sterile tiller ratios at clump peripheries than in the centres. He suggested that plants with large numbers of leaves and/or favourable growing conditions in the fall, could reach the state of development necessary for floral initiation before growth stopped in the fall. Watkins (70) noted that nitrogenous fertilizer increased and that shading decreased the proportion of fertile tillers in bromegrass. Gall (25) also suggested that factors such as temperature, light, age of plant, and nutrition could all affect the probability of flowering. On this basis, all factors in the fall of 1963 and the spring of 1964 were conducive to flowering and a high seed yield would be expected. Conversely, in 1965 a lower seed yield would be expected because of the dry conditions the previous fall accentuated by a relatively dense tiller stand. Better moisture conditions in the fall of 1965 would be expected to promote flowering in spite of crowded tiller conditions. Also, on this basis the seed yield of unfertilized areas should fall steadily for the first years after stand establishment. This trend was observed in the seed yields.

Another factor affecting seed production is the photosynthetic area during the period of seed development in early summer. This was not measured directly, but some indication of relative area between treatments was obtained by counting the number of expanded leaves on a tiller. On fertile jointing tillers, leaf exsertion had effectively ended by the end of May. In 1964 and 1966, the number of leaves per tiller during June and July remained relatively constant at nine for all treatments. In 1965, only eight leaves were present during the same period. Similarly, the range of leaf numbers in 1964 and 1966 was from six to fourteen, while in 1965, the range was from five to twelve. Both the averages and ranges decreased slightly during June and July, presumably because of leaf death and maturation of later starting tillers. No divergent effects attributable to fertilizer were observed.

It is unlikely that shading of the fertile tillers by sterile tillers would have had much effect on seed yield. At all times during internode elongation, the fertile tillers were twice as tall on the average as the sterile tillers and would thereby have the upper two or three leaves above the sterile tiller level (Figures 8 and 9).

However, the range of heights found among fertile jointed tillers was greater in 1965 than in other years, primarily because of larger numbers of shorter tillers. In 1965 some tillers were less than 20 inches long. Only from non-fertilized plots were any fertile tillers so short in 1966. Such tillers would be shaded to a considerable degree by taller tillers and it is notable that also in 1965, 31% of fertile tillers had either small sized or blind panicles, compared to 22% and 21% for the years 1964 and 1966. Most blind panicles were caused by what appeared to be a fungal infection just above the flag leaf node.

No differences in tiller growth were produced during spring and early summer by variation in the time of fertilizer application. The sterile jointing tillers produced considerably taller growth in 1965 and 1966 on all fertilized areas. In 1965, the average sterile jointing tiller from a non-fertilized area grew to a height of 15 inches by seed harvest time, while the average tiller of the same type from a fertilized area was 22 inches tall. In 1966, average heights from similar treatments were 16 inches and 22 inches respectively (Figure 8). Leaf numbers were not affected (Figure 11).

There were differences in sterile tiller characteristics between 1964 and subsequent years. There was a positive correlation between percentage occurrence and height of crown buds in 1964. No such correlation appeared in 1965 and 1966. It is suggested that the high fertility conditions and the relatively thin tiller stand in the spring of 1964, which contributed to high seed yields that year also brought about an increase in tiller density during June and July by promoting the developmental progression: crown buds → sterile rosettes → sterile jointed tillers. This would result in the phenomena observed, namely, the range of crown bud lengths close to the maximum possible (0.25 inches to 2.0 inches) (Appendix 7), the resurgence of sterile rosette tillers in July (Figures 3, 4, 5, 6), and explain some of the complex behaviour of the sterile jointed tillers.

In June and July of 1964, these tillers exhibited reductions in average height from 20 inches to 16 inches and in the number of green leaves from 8 to 9 leaves to 5 to 7 leaves for all treatments except that of midsummer fertilization. This treatment produced sterile jointed tillers in which the two characters remained relatively constant at a height of 20 inches and with 9 leaves. Under all treatments, the upper limits of height range increased steadily from 28 inches in late May to 36 inches in early July. The lower limits decreased during the same period from 10 inches to 5 inches. The green leaves produced by the tillers showed similar trends (Figure 11). Both events were probably due to the simultaneous growth of already present sterile jointed tillers and the formation of new ones with smaller dimensions from sterile rosette tillers. Formation of new sterile rosettes and sterile jointed tillers from crown buds in 1965 did not occur in the period from late May to mid-July, and in 1966, no second surge of tiller production beyond the crown bud stage took place until after the seed harvest (Figures 3, 4, 5, 6).

Yearly variation in tiller behaviour was greater than variation due to fertilizer applications. The biggest differences caused by variation in the time of fertilizer application occurred among the sterile jointed tillers. Faster regrowth in 1964 as compared to 1965 or 1966 produced a greater proportion of jointed tillers. By mid-September, 42% of the tillers in the plots fertilized in midsummer had jointed, compared to 37% in fall fertilized plots, 28% in spring fertilized plots and only 8% in plots not fertilized. These percentages had changed to 30% for the summer fertilization and to 25% for the other treatments by the end of October, largely as a result of crown bud production in the fertilized areas. The internode elongation in the tillers from non-fertilized plots under daylengths less than previous tests have shown to be required for internode elongation (25, 36) were for total stem lengths of the order of 1 to 2 inches distributed among 4 to 6 internodes - about 0.25 inches per node - a marginal internode extension which could have been a carryover effect from the time daylength was sufficient. The effect was negligible after mid-September.

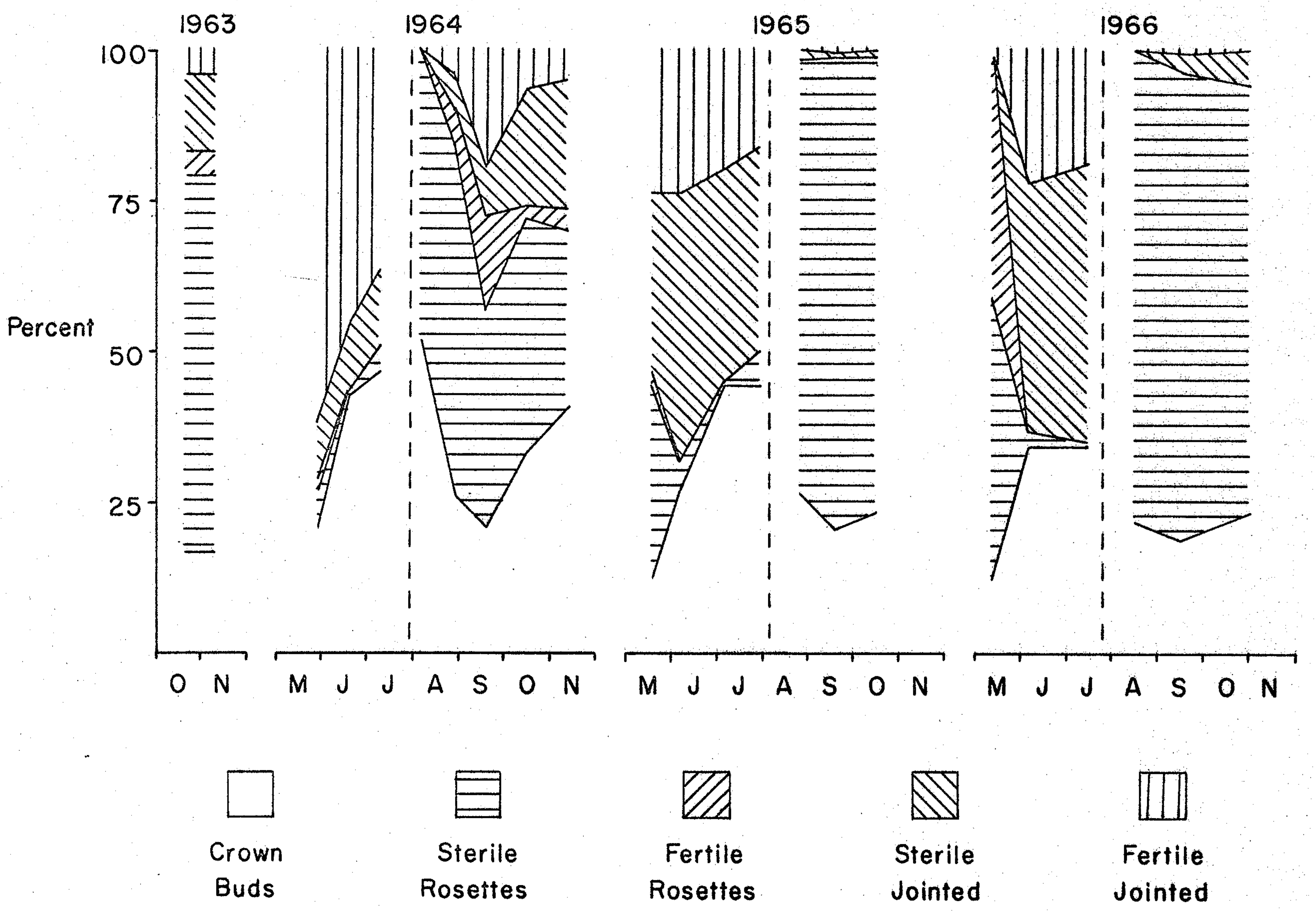
In 1965, no fertilizer effect was exhibited in the regrowth. Dry conditions at harvest time delayed regrowth with the result that less than 5% of the tillers jointed. This left 70% of the tillers as sterile rosettes and 20% as crown buds (Figures 3, 4, 5, 6).

In 1966, regrowth tillers from non-fertilized plots behaved as in 1965 - less than 5% of them jointed. In the fertilized plots, 30% of the tillers jointed, a proportion comparable to the same plots in 1964. Also, the production of new crown buds in the fall of 1966 was small in unfertilized plots, only 22% of tillers being crown buds compared with 50% in the fertilized plots (Figures 3, 4, 5, 6). The range of heights in regrowth tillers in 1964 was greater than in 1965 or 1966 (Figures 7, 8), but variation in leaf production among the same tillers remained about the same in all years (Figures 10, 11). Presumably, the plots in 1964 were still benefiting as late as early fall from better growing conditions than existed in 1965 and 1966.

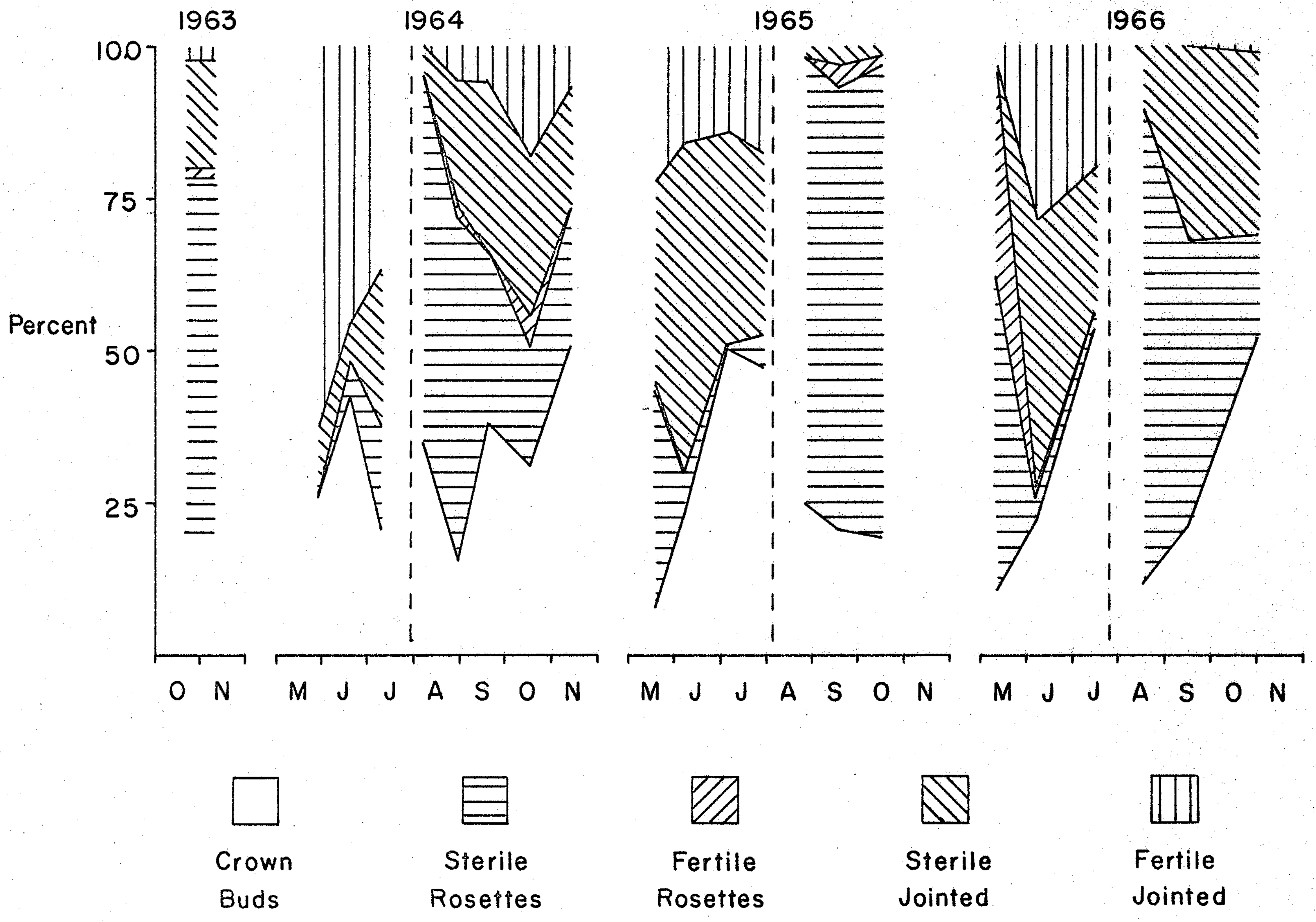
Under seed production conditions, carbohydrate content of the rhizomes was never so low as to limit bud growth. The lowest levels reached were 10% of rhizome dry weight recorded in late May and again in mid-August of 1964, both after periods of rapid growth without significant photosynthetic areas to supply nutrients. A slight increase to 20% was noted in June of 1964, presumably due to conditions favourable for carbohydrate production and storage. This slight increase did not occur in 1965 or 1966. A rapid increase in September and October probably sustained in part by breakdown of longer chain carbohydrates, left the plants with soluble carbohydrate levels of 30% to 40% of rhizome dry weight at the beginning of winter. No differences due to fertilizer were detected (Figure 13).

It should be noted that the summer tiller population in 1964 contained 10% fertile jointing tillers, a considerably higher proportion than the 2% to 3% of succeeding years. However, the same period in 1965 produced 5% of fertile rosette tillers under conditions which were not favourable for stem elongation. Fertile tiller production in 1966 was negligible (Figures 3, 4, 5, 6). It may be that favourable nutritional conditions both within and around the plants will lead to some fertile tiller production even with an unfavourable daylength. If this is so, the reduction in fertile tiller production in late summer can be considered as an indication of worsening conditions of growth for individual tillers as the stand ages.

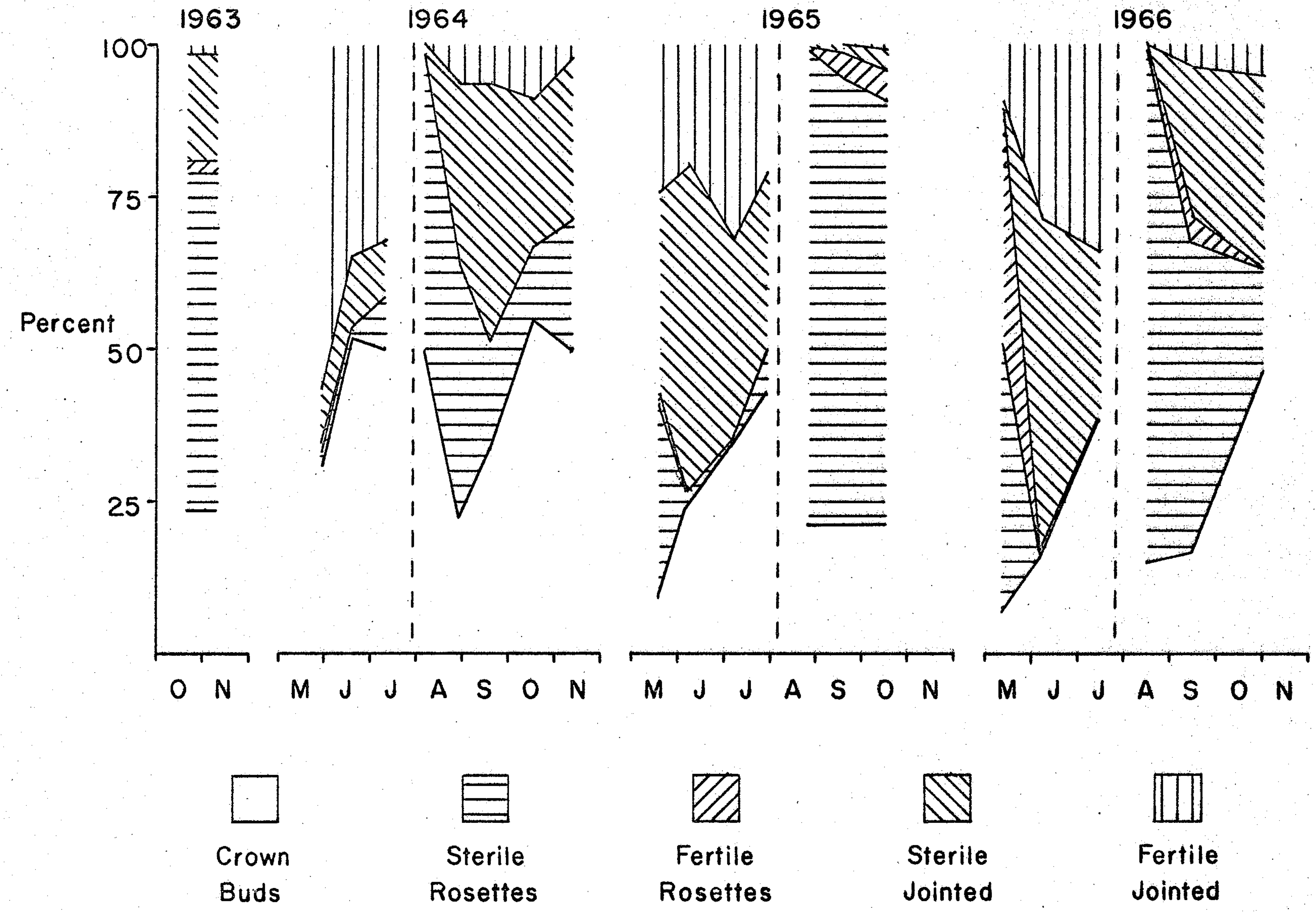
Relative proportions of the five tiller types in bromegrass grown for seed on a non-fertilized area



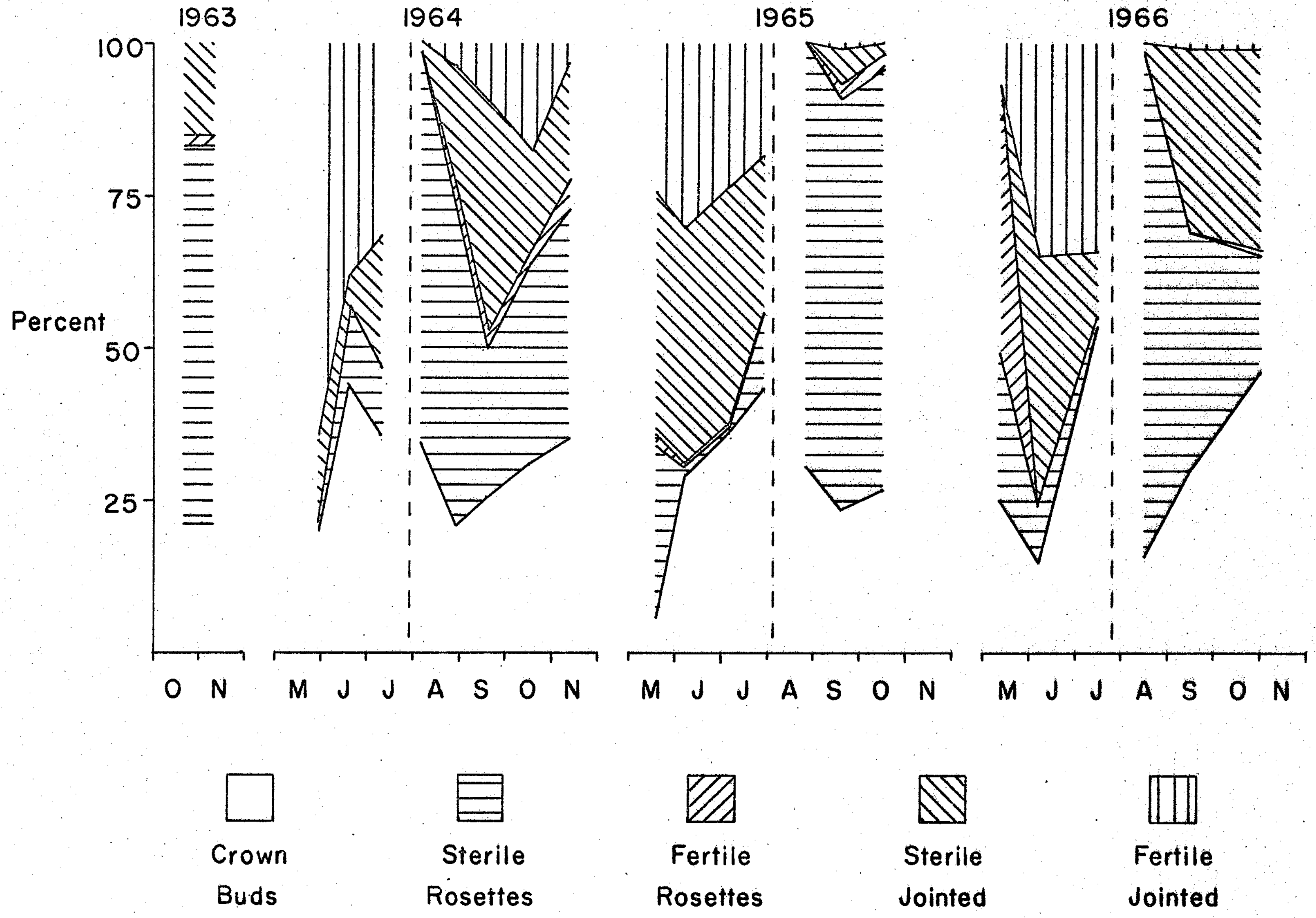
Relative proportions of the five tiller types in bromegrass grown for seed on an area fertilized in spring



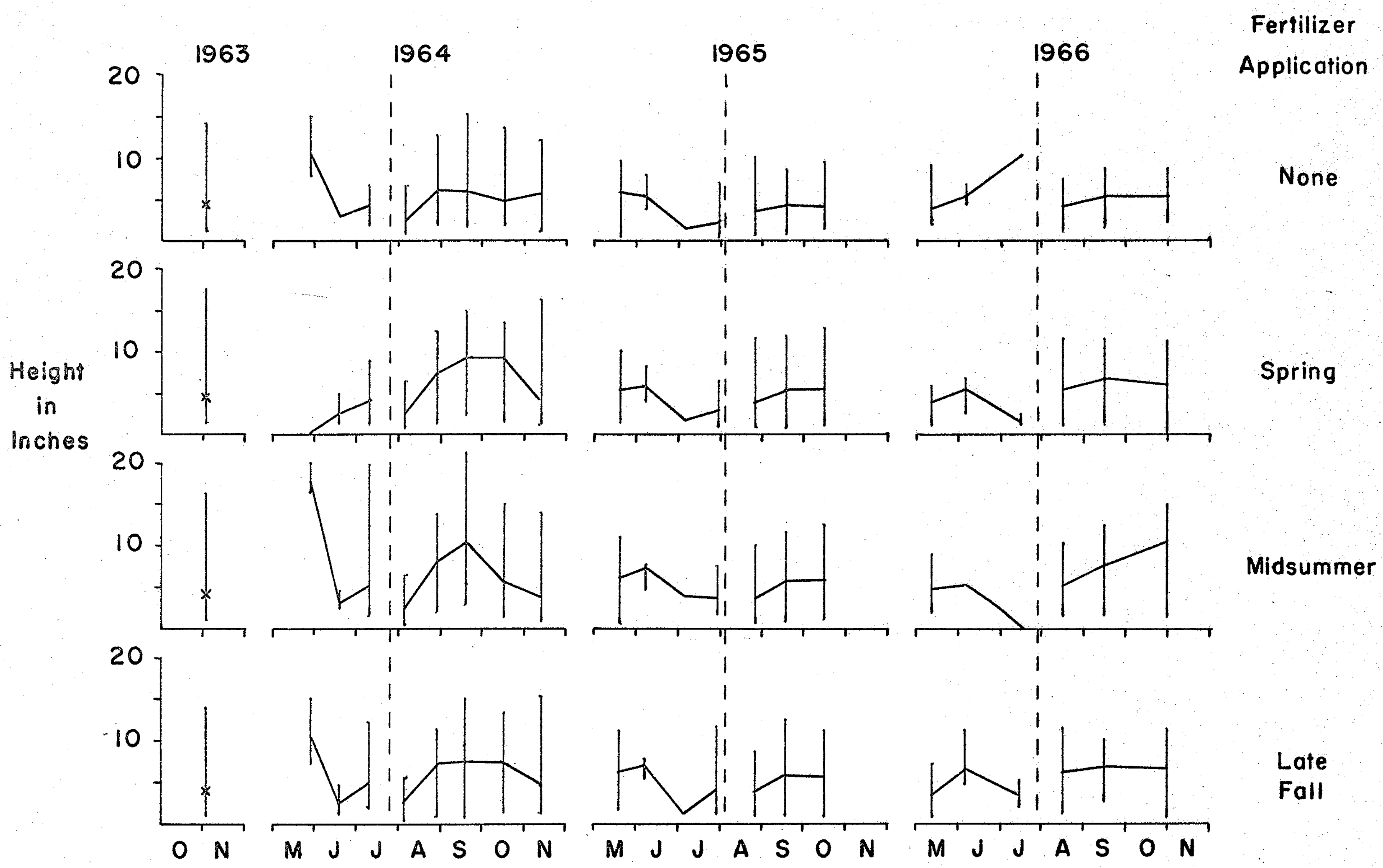
Relative proportions of the five tiller types in bromegrass grown for seed
on an area fertilized in midsummer



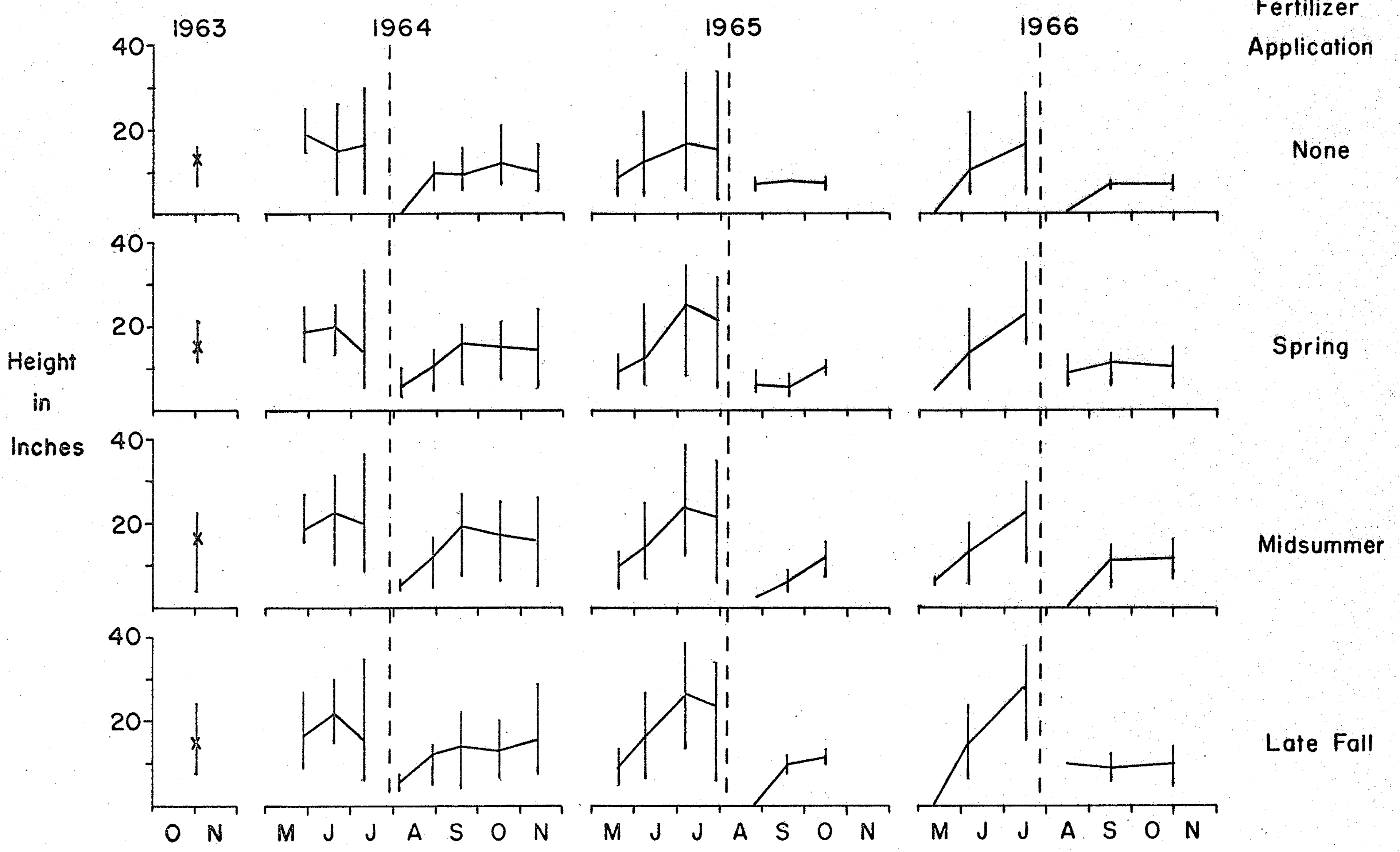
Relative proportions of the five tiller types in bromegrass grown for seed on an area fertilized in late fall



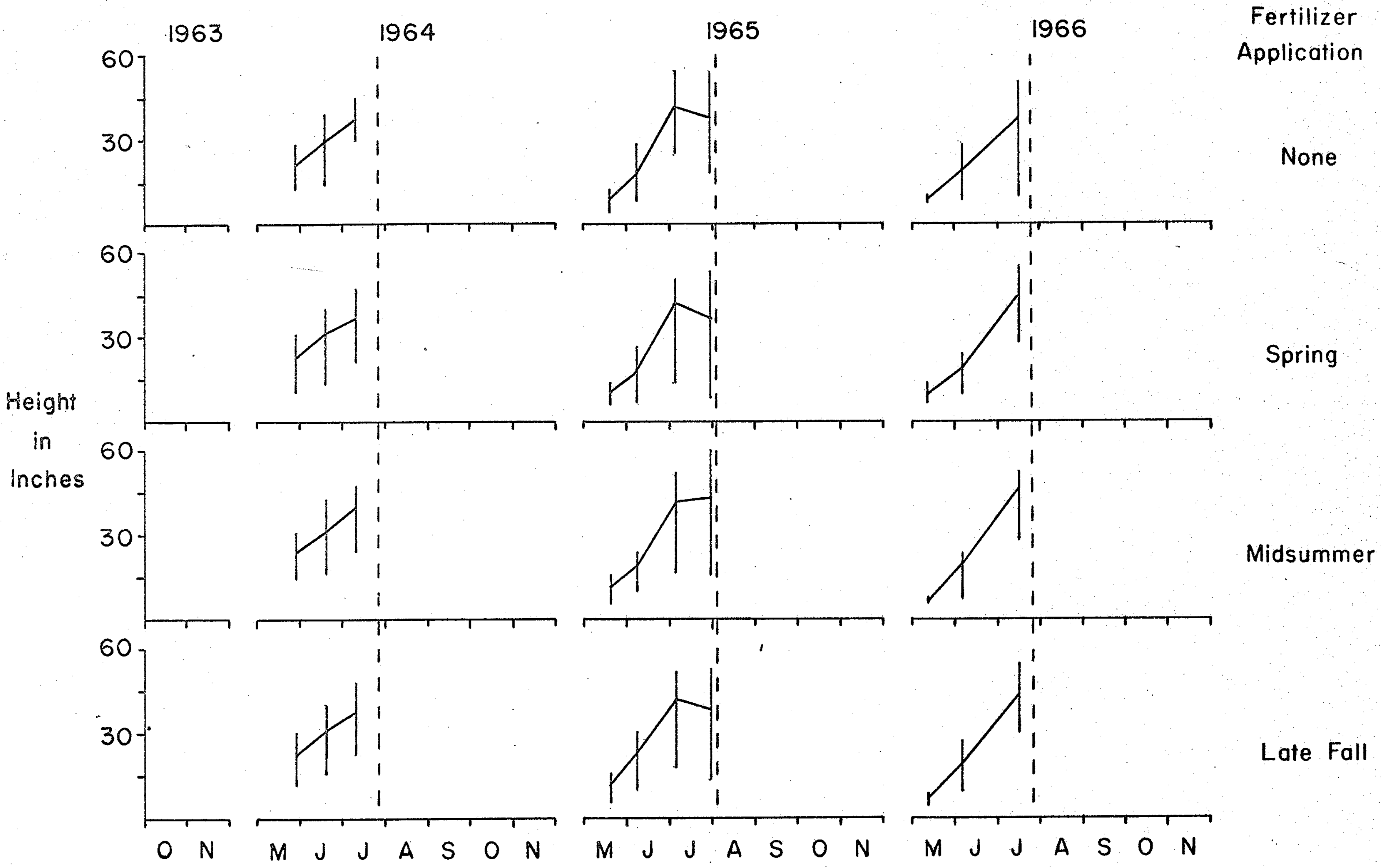
Height of sterile rosette tillers in bromegrass grown for seed



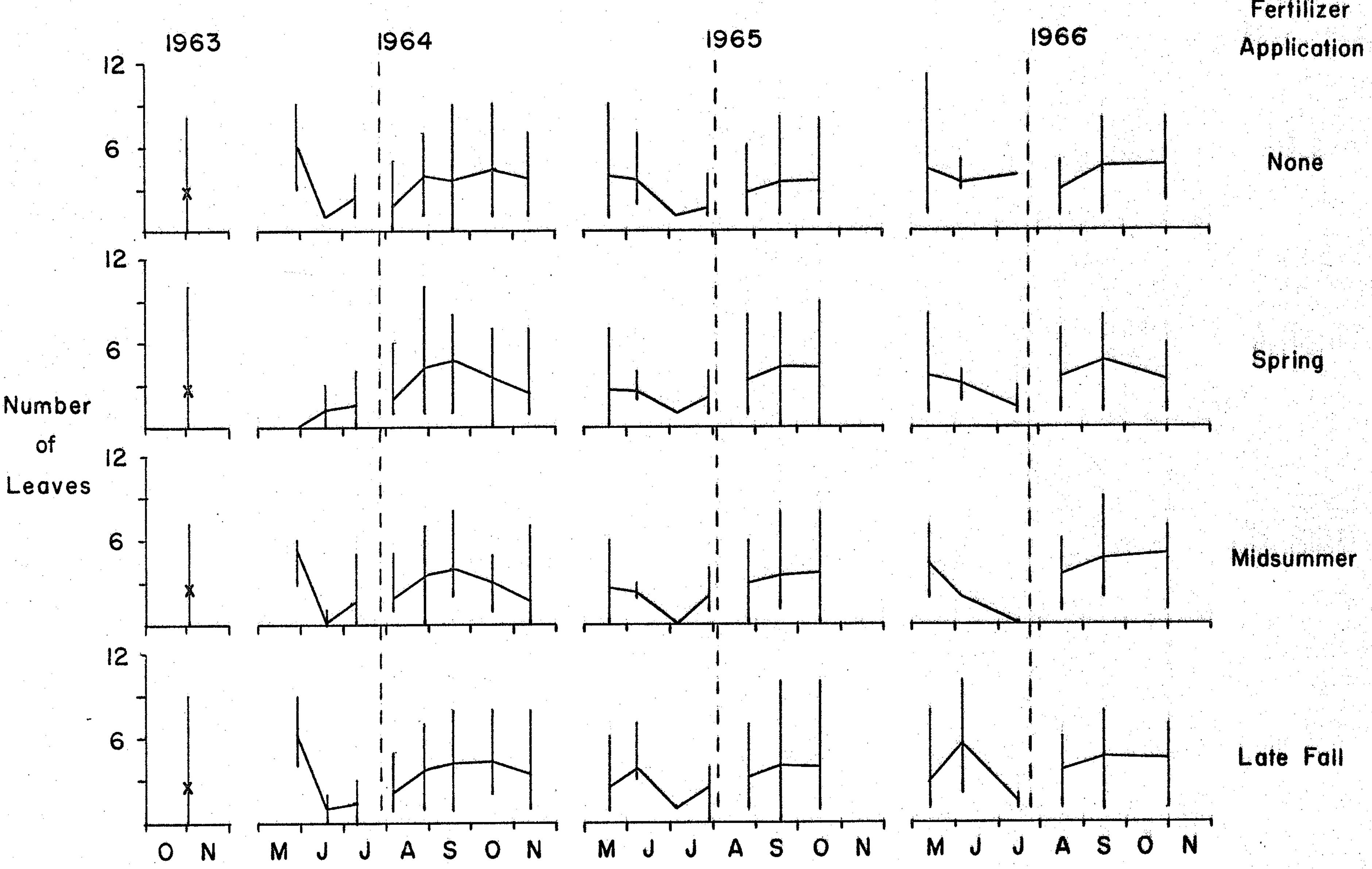
Height of sterile jointed tillers in bromegrass grown for seed



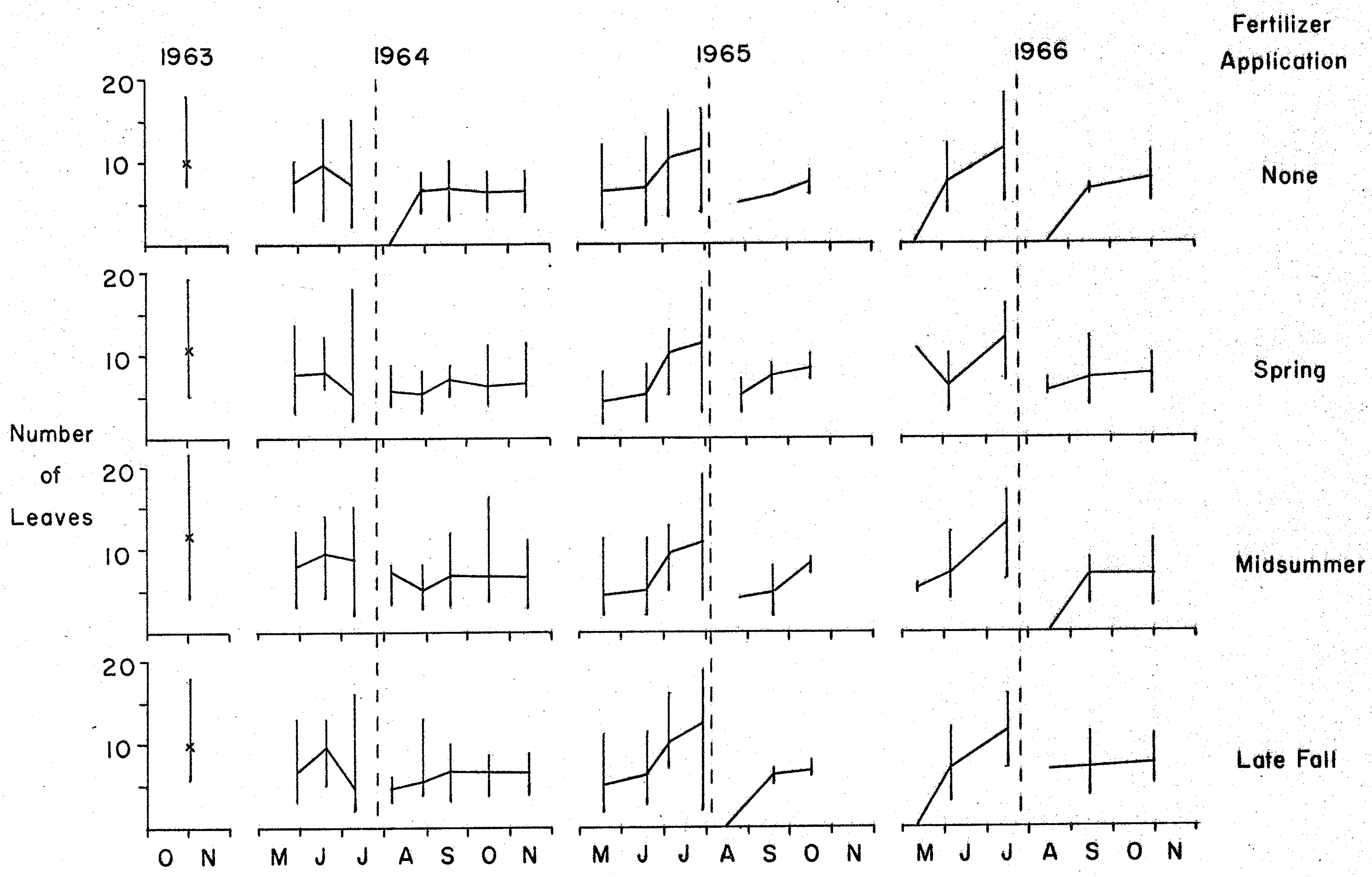
Height of fertile jointed tillers of bromegrass



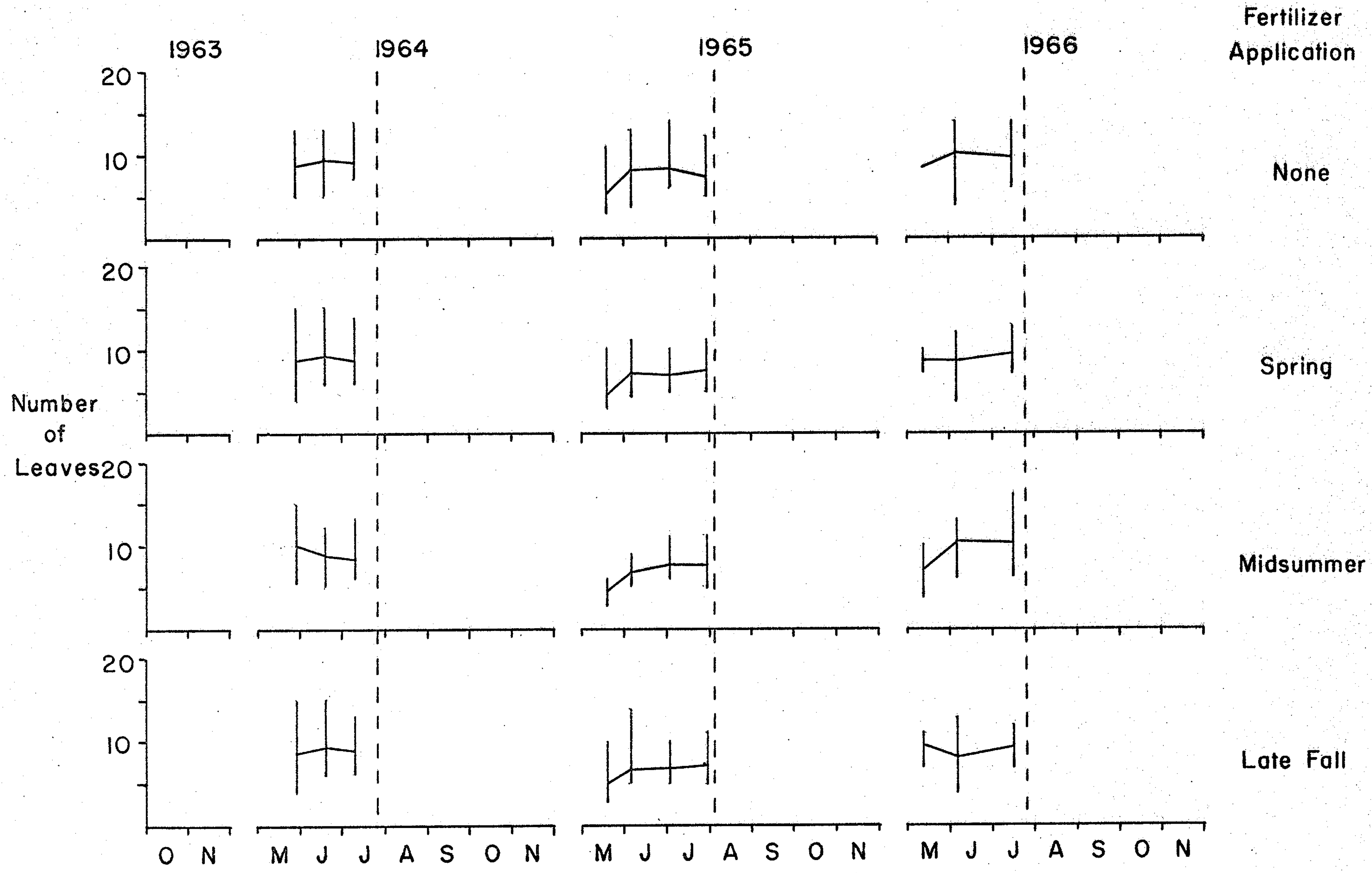
Number of leaves on sterile rosette tillers from bromegrass grown for seed



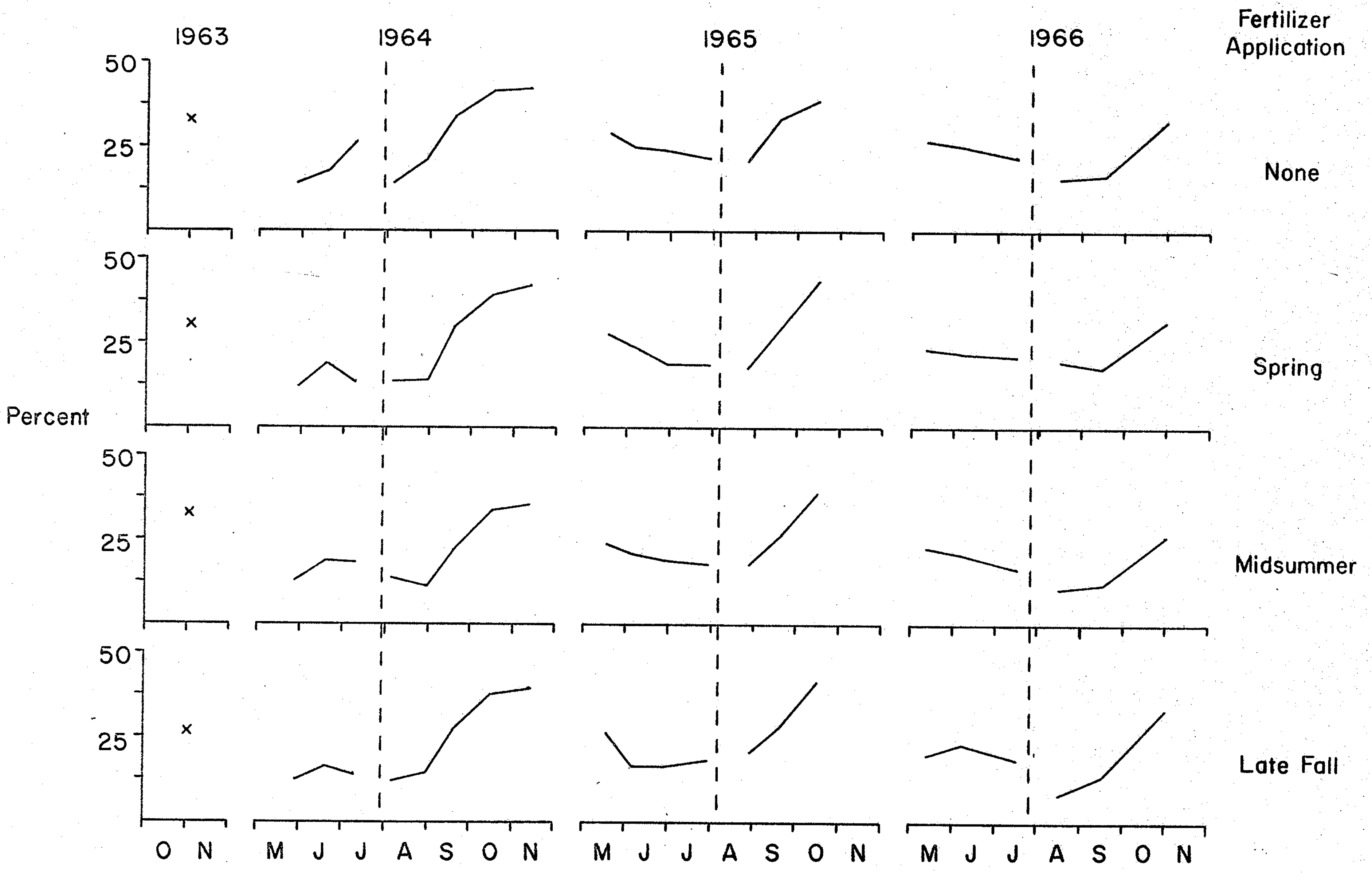
Number of leaves on sterile jointed tillers from bromegrass grown for seed



Number of leaves on fertile jointed tillers of bromegrass



Acid soluble carbohydrate percentage content of rhizomes of bromegrass grown for seed



B. Forage Production

1. One Cut Per Year at the Hay Stage

Agronomic yields are presented in Table 6 as tons of dry matter per acre. Total hay production in the three harvest years from non-fertilized plots was 8.7 tons dry matter per acre of which 3.1 tons was produced in the first harvest year. Subsequently, production declined annually by 6%, a non-significant ($p > 0.05$) reduction (Appendix 11). The spring application of fertilizer boosted total yield to 10.3 tons dry matter per acre but here too, yields decreased steadily as the stand aged. The midsummer fertilizer application resulted in a significant ($p < 0.05$) increase in yield over the check area in 1964 and the late fall fertilizer application produced a similar increase ($p < 0.06$) over the check yield in 1966 (Table 6, Appendix 12). Both midsummer and late fall fertilizer treatments resulted in three year total dry matter yields of 11.3 tons per acre, significantly higher ($p < 0.10$) than production from the check plots.

It is clear that the application of fertilizer has led to consistent increases in hay yields. There also appeared to be a slight superiority in production from plots which received fertilizer after the hay crop had been removed, when compared with plots receiving fertilizer in spring. However, the differences did not consistently reach a statistically significant level ($p = 0.05$). Previous reports have presented similar results from diverse areas in North America (7, 9, 14, 33, 41, 43, 66, 71). Fertilizer rates currently recommended in Manitoba are slightly higher than the 50 pounds/acre of nitrogen used in this experiment (12), and it is possible that greater yield differences might have been obtained if a higher fertilizer rate had been used.

Crude protein yields from bromegrass harvested for hay are presented in Table 7. Five missing samples from the 1964 results necessitated estimating their protein production from their dry matter yields. Since the correlation between dry matter and protein production for the eleven samples available was 0.97, it is probable that little loss of information was caused by the missing results. Nevertheless, the 1964 protein yield estimates were not included in the analyses of the data for differences in protein yield between treatments (Appendix 14) or for differences in production between years (Appendix 13). However, results in all years indicated that fertilizer application, particularly in spring and fall, increased protein production.

Protein production from the non-fertilized plots was 554 pounds per acre in 1964, 383 pounds per acre in 1965, and 299 pounds per acre in 1966. Spring or fall fertilizer applications produced protein increases of 30% in 1964, 40% in 1965 and 50% in 1966 over the production from non-fertilized areas. Summer applications of fertilizer appeared to have less effect on production; the higher yields for this treatment in 1964 may be as much related to weed control in 1963 as to fertilizer application.

Although the agronomic differences in protein yield between fertilized and non-fertilized areas were clear and consistent from year to year, statistical analyses of the results revealed significant differences ($p < 0.10$) between fertilizer treatments only in 1966 (Table 7, Appendix 14). Yields in 1966 were significantly lower ($p < 0.01$) than those of 1965 (Appendix 13). Protein production showed a distinct reduction as the stand aged (Table 7), unlike dry matter production (Table 6) which remained relatively constant, particularly when the plots were fertilized. The results confirm previous conclusions (8, 13, 21, 44, 66) that nitrogenous fertilizer increases crude protein production in bromegrass.

The tiller development pattern in brome grown for hay (one cut per year at the early flowering stage of growth) is presented in Figures 14 - 24 and Appendices 15 - 18.

The proportion of tillers in the samples taken in November 1963 were: - crown buds - 20%; sterile rosettes - 77%; sterile jointed tillers - 1%; and fertile tillers - 2% (Figures 14, 15, 16, 17). The average length of the crown buds was 0.8 inches with the range from 0.25 to 2.0 inches, the maximum attainable (Appendix 15). The number of leaf primordia around the crown bud growing point averaged 6, and varied between 4 and 9. The average height of the sterile rosettes was 4.5 inches and ranged up to 10 inches (Figure 18), while the number of green leaves was 3.5 on average and ranged from zero to 10 (Figure 20). The fertilizer treatments applied had no apparent effect on the growth of crown buds or rosette tillers.

Table 6

Hay production from "Lincoln" bromegrass as influenced by fertilizer applications at Winnipeg

Time of fertilizer application	Yield by harvest year (tons dry matter/acre)			Three year total yield
	1964	1965	1966	
None applied	3.1[#]	2.9	2.7	8.7
Spring	3.6	3.4	3.3	10.3
Midsummer	4.2	3.5	3.6	11.3
Late Fall	3.9	3.5	3.9	11.3
Standard error	0.5	0.4	0.3	1.2

[#] Yields are the average of four replicates

Table 7

The influence of fertilizer on crude protein production by "Lincoln" bromegrass harvested for hay at Winnipeg

Time of fertilizer application	Yield by harvest year (lbs. crude protein/acre)			Two year total yield
	1964[1]	1965	1966	
None applied	554[2]	383	299	682
Spring	650	652	546	1198
Midsummer	755	510	414	924
Late Fall	706	636	584	1223
Standard error		76	70	146

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[1] Some missing data. No comparisons made. Not included in totals

[2] Yields are the average of four replicates

As the plots intended for hay production were trimmed to three inches on September 21st, most of the jointed tillers were eliminated. Consequently, in the tiller samples taken in November, the frequency of sterile rosettes was relatively higher than in comparable seed production plots. However, the addition of fertilizer and its time of application influenced the growth of the few sterile jointed tillers remaining. Average height increased from 6.0 inches for check plots to 7.25 and 8.25 inches for spring and midsummer applications respectively. Heights ranged from 4.0 inches to 9.0 inches for all treatments (Figure 19). Fertilizer application also appeared not to influence either green leaf production or the number of internodes which elongated. In all treatments, an average of 8 leaves (range 6 to 9) and 5 leaf primordia (range 4 to 8) were produced (Figure 38). Similarly, an average of 6.25 internodes showed some elongation (range 3 to 8) in both fertilized and non-fertilized sterile jointed tillers (Appendix 16).

The tendency for overlapping in the ranges of plant parts between crown buds and sterile rosettes, and between sterile rosettes and sterile jointed tillers occurred with all fertilizer treatments, and suggests that continuous crown bud production and further development was not interrupted by trimming the tillers to a height of three inches in September.

During the early spring growth phase, tiller development in plots cut for hay was similar to the growth in the plots harvested for seed. The lowest percentage of crown buds for all treatments, 5% in 1965 and 10% in 1966, occurred in mid-May. Subsequently, they increased in number (30% to 55%) up to the time of the hay cut in late June or in July. Thus, at the time of the hay cut in late June, 1964, 45% of the tillers were crown buds. In 1965, the spring application of fertilizer raised crown bud proportion to 55% while for other treatments only 40% of the tiller population was at the crown bud stage. Fall fertilized plots averaged 55% crown buds by early July, 1966, while plots fertilized in mid summer had 45%, and the other plots had only 30% crown buds (Figures 14, 15, 16, 17).

Rosette tillers reached a maximum in mid-May; May 11, 1966, 45% of the tiller population was at the sterile and 40% was at the fertile rosette stage. Jointing tillers made up about 5% of the tiller population (Figures 14, 15, 16, 17). From then until early June, the proportions of rosette tillers steadily decreased to zero as internodes elongated. During June, jointed tillers decreased (Figures 14, 15, 16, 17). As there was no observable quantity of dead tillers, the number of jointed tillers probably remained constant while tiller density per unit area increased as a result of an increase in the number of crown buds.

In late June, 1964, the hay harvest reduced the tiller population to half its previous level. The 1965 harvest removed 45% of the tillers from the plots fertilized in spring and 60% from the remaining plots whilst in 1966, the percentage of tillers harvested was 44 from fall fertilized plots and 60 from all other treatments. (Figures 14, 15, 16, 17).

The average heights of the sterile jointed tillers increased rapidly from 5 inches in mid-May to 20 to 30 inches by harvest time (Figure 19). Green leaf production showed a similar increase, from 5 in May to 10 by the end of June (Figure 21). In 1965 and 1966, tillers from the non-fertilized plots grew more slowly than those from fertilized plots and reached average heights of 20 inches in both years. The fall fertilizer application had the greatest effect on height in 1966 when the sterile jointed tillers averaged 32 inches high. In 1965, both fall and summer applications of fertilizer resulted in average heights of 26 inches in sterile jointed tillers and in 1964 the mid-summer fertilizer application resulted in tillers of 20 inches average height compared to a 13 inch average height with other treatments (Figure 19).

Sterile jointed tillers at hay harvest ranged from 7 to 40 inches in height. The only exception to this was the narrow 25 - 37 inch range observed in 1966 in fall fertilized plots. The range of green leaf numbers on sterile jointed tillers changed from 2 to 10 in mid-May to 4 to 16 just before the hay harvest (Figure 21). No differences appeared between treatments in any year.

The number of elongating internodes in the sterile jointed tillers increased rapidly during late May and June from 3 to 9 in 1965, and from 4 to 10 in 1966. In 1964, only 6 internodes were extended on the average (Appendix 16). The height above ground of the growing points of the sterile jointed tillers was 10 to 15 inches by harvest time in 1965, and 15 to 25 inches by the same time in 1966. In each year, growing points in the non-fertilized plots were elevated the least. After mid-June, the majority of the growing points of jointed tillers were above the normal mowing and grazing heights irrespective of fertilizer treatment.

Fertile jointed tillers developed as in plots for seed production (Figures 9, 12; Appendices 8, 10). They elongated approximately twice as fast as the sterile tillers and headed in mid-June. By the time of the hay harvest they were 40 inches high (Figure 9), had 7 to 10 leaves (Figure 12) with 6 to 7 elongated internodes (Appendix 10). Observations suggested that the leaves were much bigger on average than those on sterile tillers which would compensate, at least in part, for the fewer number of leaves.

The tiller samples were separated into leaves and stems for dry weight comparisons. As the crown buds were very small, and the rosette tiller stage had essentially disappeared by the beginning of June, leaf samples by harvest time consisted almost entirely of material from the jointed tillers. Stem samples in entirety were from jointed tillers. No separation into fertile or sterile tiller material was made. In all years, leaf production by the fifty tiller samples was about 15 grams of dry matter by harvest time (Figure 22). Differences between fertilizer effects in 1965 resulted in the non-fertilized plots producing a slightly higher leaf weight, and the plots fertilized in spring a lower leaf weight. More leaf material was produced by the non-fertilized areas in 1966 also, based on the 50 tiller samples (Figure 22).

Stem production on a dry weight basis was 11 to 12 grams in 1964 and 1965 with no great differences between treatments. In 1966, plots receiving the spring or mid-summer fertilizer treatment produced 15 grams of stem material per tiller sample, while the other plots produced 20 grams per sample (Figure 23).

It appeared that non-fertilized areas produced shorter, heavier tillers in 1966, but the stem/leaf ratio was not affected. It should be noted that during June in all years stem dry matter tripled in quantity while leaf dry matter increased by 30% at most (Figures 22, 23). At the same time, protein content of the leaves fell from 15% to 10% of the dry weight (Appendix 17), and stem protein content fell from 8% to 2% to 4% (Appendix 18).

Variation in the amount of dry matter produced by 50 tillers (Figures 22, 23) did not account for the equal or greater yields of hay produced by a lower proportion of jointed tillers in the spring fertilized plots of 1965 and the fall fertilized plots in 1966 (Table 6). Nor could yield differences be accounted for by variations in the fertile/sterile tiller ratio (Figures 14, 15, 16, 17). The yield differences must have been due to a higher tiller density.

The hay harvest removed almost all the photosynthetic material (Figures 20, 21, 22, 23). After harvest the crown buds grew vigorously and had produced one or more green leaves within ten days. Approximately three weeks after harvest, the number of crown buds in the population was about 30% and 20% in 1964 and in 1965 and 1966 respectively. From these minima, the crown buds increased slowly to 30% to 40% of the tiller population by late fall. No differences between fertilizer treatments were apparent in crown bud growth until 1966. In 1964, crown buds continued to be produced and to grow to subsequent stages of development (sterile rosettes, sterile jointed tillers) throughout the summer. All sizes from recently produced 0.25 inch buds to 2 inch buds about to produce a green leaf were present (Appendix 15). Leaf initial number ranged from 4 to 9 with an average of 7 over the whole summer growing season. In 1965, a slight pause in crown bud development to sterile rosettes was apparent in August, probably because of the sudden mass growth after the hay harvest. This pause in development was evident as a smaller average length and a reduced maximum value in height. In September, 1966, a similar pause in development was particularly evident in non-fertilized plots (Appendix 15). Crown buds from non-fertilized areas also had a lower average height (Appendix 15) and a lower average number of leaf initials than did the crown buds from other treatment areas. The ranges of leaf initial numbers present were not affected by any fertilizer treatment in either 1965 or 1966.

Some 75% of the tillers left at the hay cut had developed to the sterile rosette stage three weeks after the harvest date. Also in 1964 and 1965, some tillers had started to joint within this time, particularly in the plots receiving the spring application of fertilizer. Under the no fertilizer treatment, growth was slower and jointing did not occur quite as soon after the harvest cut. Thirty days after the hay harvest, the proportion of sterile rosettes had dropped to 50% and shortly after levelled off at 20% to 40% depending on the treatment received (Figures 14, 15, 16, 17).

In the fall of 1964, the non-fertilized treatment had a slight but consistently higher proportion of sterile rosettes in the tiller population than had the fertilized plots. In the same period of 1965, the proportion of sterile rosettes increased to 50% in plots fertilized in summer and late fall and remained at 30% in the other plots. In 1966, few tillers jointed in the non-fertilized plots, until early September and then only poorly. As a result, the proportion of sterile rosettes in the population remained at 80% until September and then fell to 60% by the end of October (Figures 14, 15, 16, 17).

In 1964 and 1965, jointed tillers were produced more rapidly in the plots fertilized in spring. At the beginning of August in 1964, 35% of the tillers in the plots fertilized in spring had jointed, whereas only 18% had jointed in the other fertilized plots and only 12% had jointed in the non-fertilized plots. By mid-September, there was no difference in jointed tiller numbers in the fertilized plots; all had 40%. The non-fertilized plots had only 30% jointed tillers. By the end of the growing season only 20% to 30% of the tillers had jointed (Figures 14, 15, 16, 17). The apparent loss of jointed tillers was due to the prevention of further jointing by the shorter daylengths in the fall.

Tiller populations in 1965 showed similar changes to the 1964 populations. By the end of August, plots fertilized in spring had 55% of their tillers with extended internodes. The non-fertilized plots had only 35% of their tillers at the jointing stage. By the end of the growing season, both areas had only 35% of their tillers at the jointed stage. Plots fertilized in summer or fall had only 27% jointed tillers. In 1966, no differences were evident between the proportions of jointed tillers in the fertilized plots. By mid-September, 35% to 40% of the tillers were at the jointed stage and this proportion had fallen only slightly by November. In the non-fertilized plots, only 10% of the tillers had jointed by the end of the growing season (Figures 14, 15, 16, 17).

Little fertilizer effect was observed at the rosette tiller stage in the summer growth. Non-fertilized plots produced slightly shorter tillers in August, 1966, when their average height was 5 inches as opposed to a 6 inch average for the tillers from fertilized plots. The same difference was maintained in September. Rosette tillers from plots fertilized in the summer of 1966 showed an increase in height to 10 inches by the end of October, while the other treatments showed no change from the previous month or even a loss in average height. This growth was probably due to the effect of the added fertilizer although no differential growth was observed in the same period in 1964 and 1965. Rosettes from plots fertilized in late fall showed reductions in height and in leaf number during early fall in all years (Figures 18, 20), probably because of crown bud development to small rosettes (Figures 14, 15, 16, 17).

The number of green leaves present on the rosette tillers showed trends very similar to height. In all years, the tillers produced 3 to 4 leaves. In 1964, tillers from the non-fertilized areas produced half a leaf more on average than did the tillers from fertilized plots. No differences appeared in other years (Figure 20).

Variation of sterile rosette tillers in both height and green leaves was greatest in 1964. In all years, the smallest rosettes were 1 to 2 inches high and had only one leaf at all summer sampling dates. This showed that new rosettes were being produced continually from crown buds. The tallest rosettes in 1964 were 20 inches high, had 9 leaves and were present in samples taken after the end of August. In subsequent years, the tallest tillers were 13 inches high and had 7 leaves (Figures 18, 20).

Sterile jointed tiller recovery growth after the hay harvest was similar in all years, but only in 1964 did they approach the size of those present before the harvest. In all years, heights reached 10 inches by mid-August. In 1964, growth continued until the average height of the jointed tillers from fertilized plots was 15 to 17 inches. In 1965 and 1966, little growth occurred beyond the 10 inch average (Figure 19). In all years, jointed tillers from the non-fertilized areas were 2 to 4 inches shorter than those from fertilized areas (Figure 19). At no time were sterile jointed tillers shorter than 5 inches. By the end of August of 1964, the tallest ones were 25 inches high, wheres in 1965 and 1966, they were only 15 inches high at the same time of year (Figure 19).

Leaf production remained similar in all three years at 6 to 7 leaves per tiller. In all years, jointed tillers had at least 3 leaves by the end of August, but had a maximum of 15 leaves in 1964 but a maximum of only 12 in 1965 and 1966 (Figure 21). No differences in leaf production were evident between the different fertilizer practices.

The height above soil level of the growing point of the sterile jointed tillers was 3 inches on average in both 1965 and 1966. This average was reached in mid-September in 1965 but not until October in 1966. In both years, non-fertilized plots showed less internode elongation in the summer growth. This shorter growth was contributed in part by fewer elongating internodes (Appendix 16).

Development of fertile tillers after the hay cut was minimal except in 1964, when 5% of the tillers sampled showed evidence of inflorescence development.

The much poorer growth in summer compared to that made in spring was most clearly shown by the amounts of oven dry material produced by the above ground parts. The 50 tiller samples produced some five grams of leaf material (Figure 22) and less than one gram of stem material (Figure 23) each summer. Little difference was exhibited between either years or fertilizer treatments although the spring fertilizer application produced slightly higher amounts of material each year.

Crude protein content of leaves was similar in the summer growth to that in the spring material at the same stage of development. Protein as a percentage of the dry weight decreased from 20% two weeks after the hay cut to 10% by the middle of September when growth slowed down because of low temperatures (Appendix 17). The protein content of samples from non-fertilized areas was invariably lower than from other samples but not markedly so. Stem protein also declined from 10% shortly after the hay harvest to 5% in mid-September (Appendix 18). As the amount of stem in a tiller sample was small, fluctuations of stem protein in summer are considered to be of small importance from a practical viewpoint. Protein content showed no marked year to year or fertilizer treatment variations.

Soluble carbohydrate levels in the rhizomes behaved differently in 1964 compared to the following years. In 1964 there was an initial increase in the percentage of soluble carbohydrate from 15% at the end of May to 20% in mid-June. This increase is interpreted as a recovery from low carbohydrate levels to which the rhizomes had been reduced by growth demands in the early spring. In 1965 and 1966, the carbohydrate content of the rhizomes was 20% to 25% of dry weight in early and mid-May (Figure 24). Presumably, the level at the start of spring growth in April was even higher. In all years, carbohydrate levels declined from their spring high values to 10% of rhizome dry weight two weeks after the hay harvest. Clearly, spring growth and recovery growth used more carbohydrates than the tillers could manufacture.

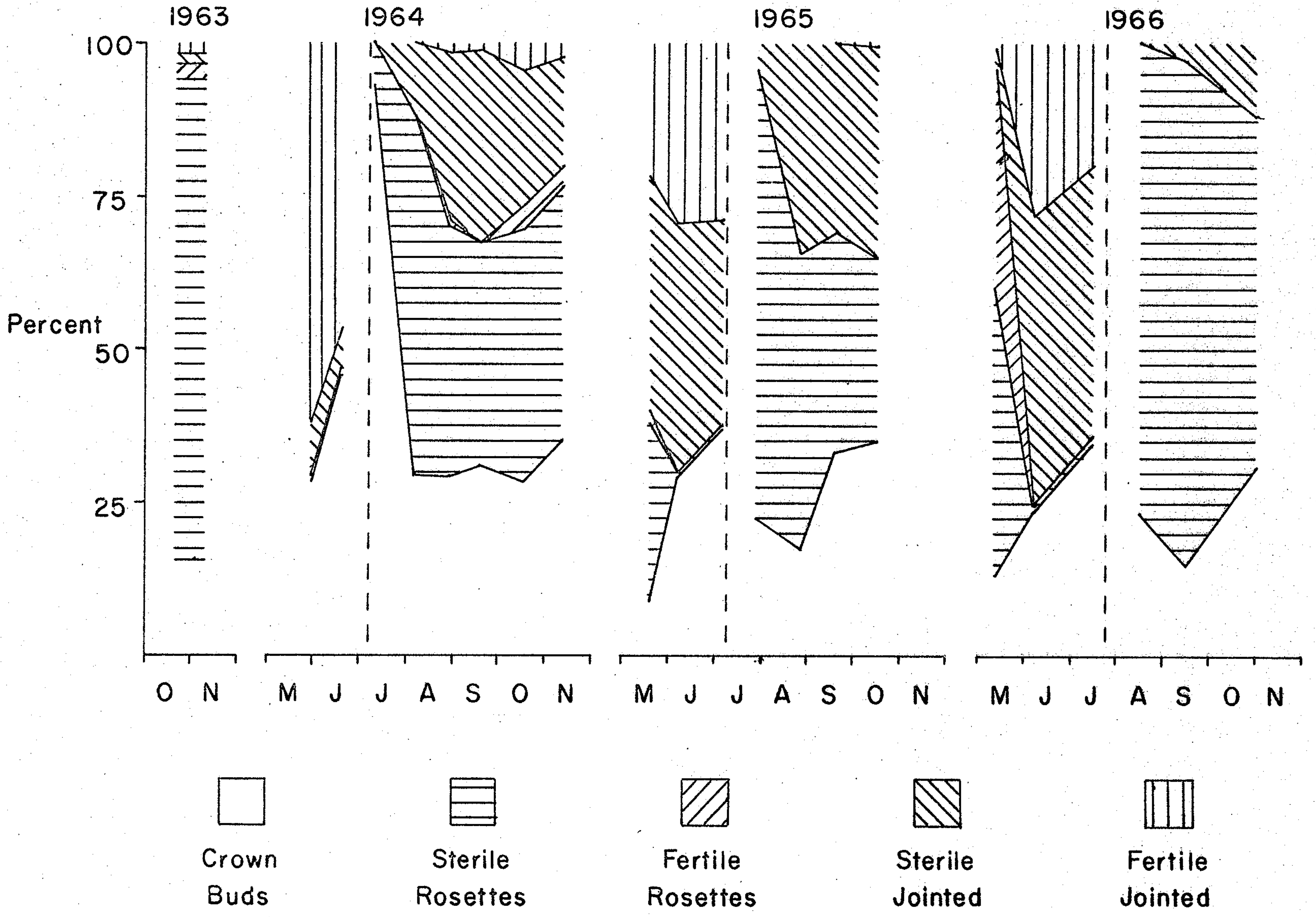
From the low storage levels after harvest, rhizome carbohydrate content increased rapidly to 40% of dry weight by mid-October (Figure 24). A difference appeared after the mid-summer fertilizer application. Rhizomes from plots receiving fertilizer in summer contained 5% less carbohydrate by mid-September than rhizomes from plots subjected to other fertilizer practices. However, by the middle of October, differences in carbohydrate content had disappeared from rhizome samples from all plots (Figure 24).

2. Two Cuts Per Year Simulating Rotational Grazing

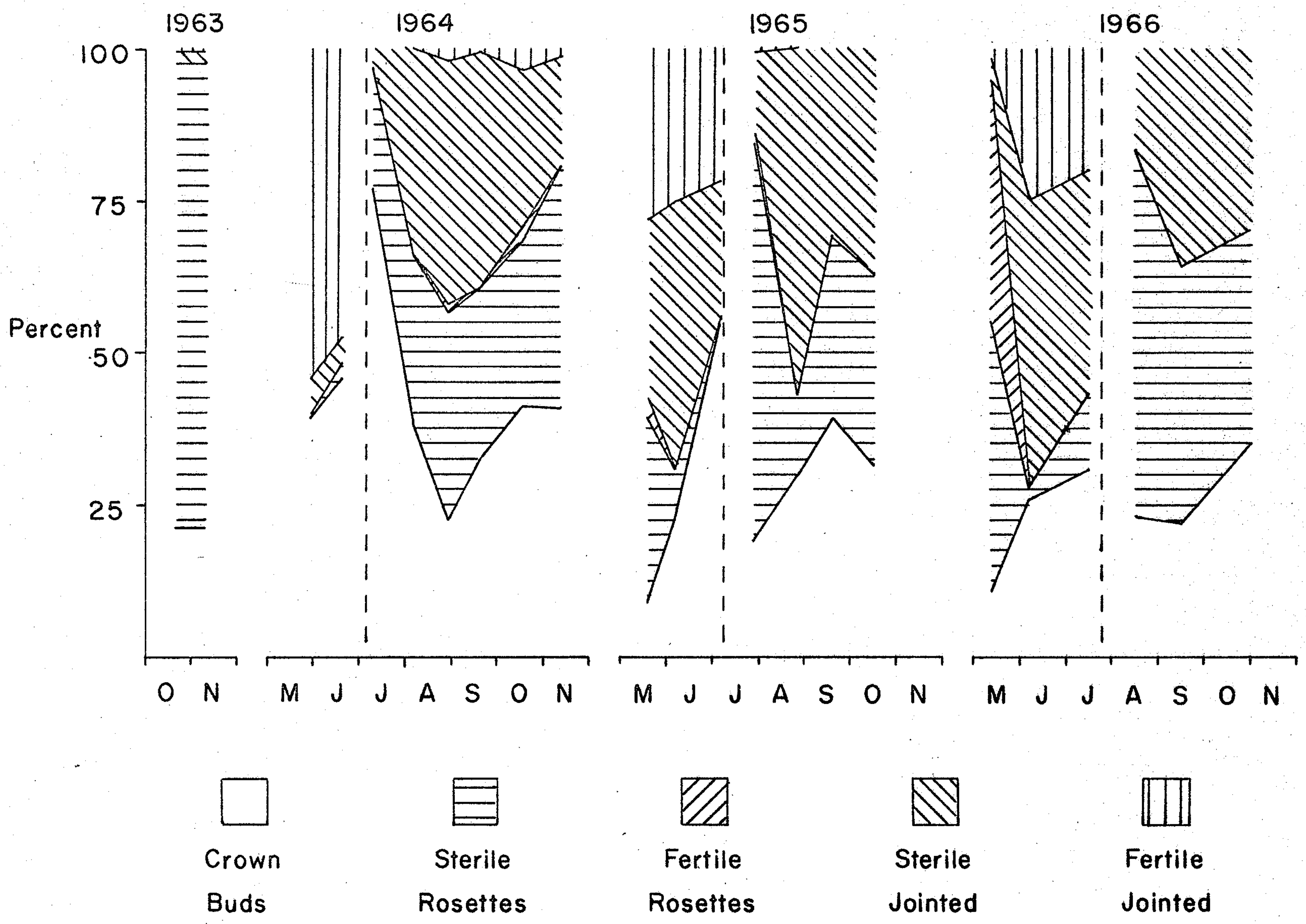
Dry matter production from each harvest, for each year and the total production for the three harvest years is presented in Table 8. The stage of development which bromegrass had reached at harvest time varied from year to year. In 1964, the first cut was taken early in June, shortly after the seed heads had emerged from the flag leaf sheath. The second cut was taken in mid-August. In 1965 and 1966, the first cut was made in late June, at anthesis, while the second cut was taken late in September in 1965 and early in October in 1966, when growth had been checked by cool temperatures.

Yields of dry matter from the first harvest cut in the years

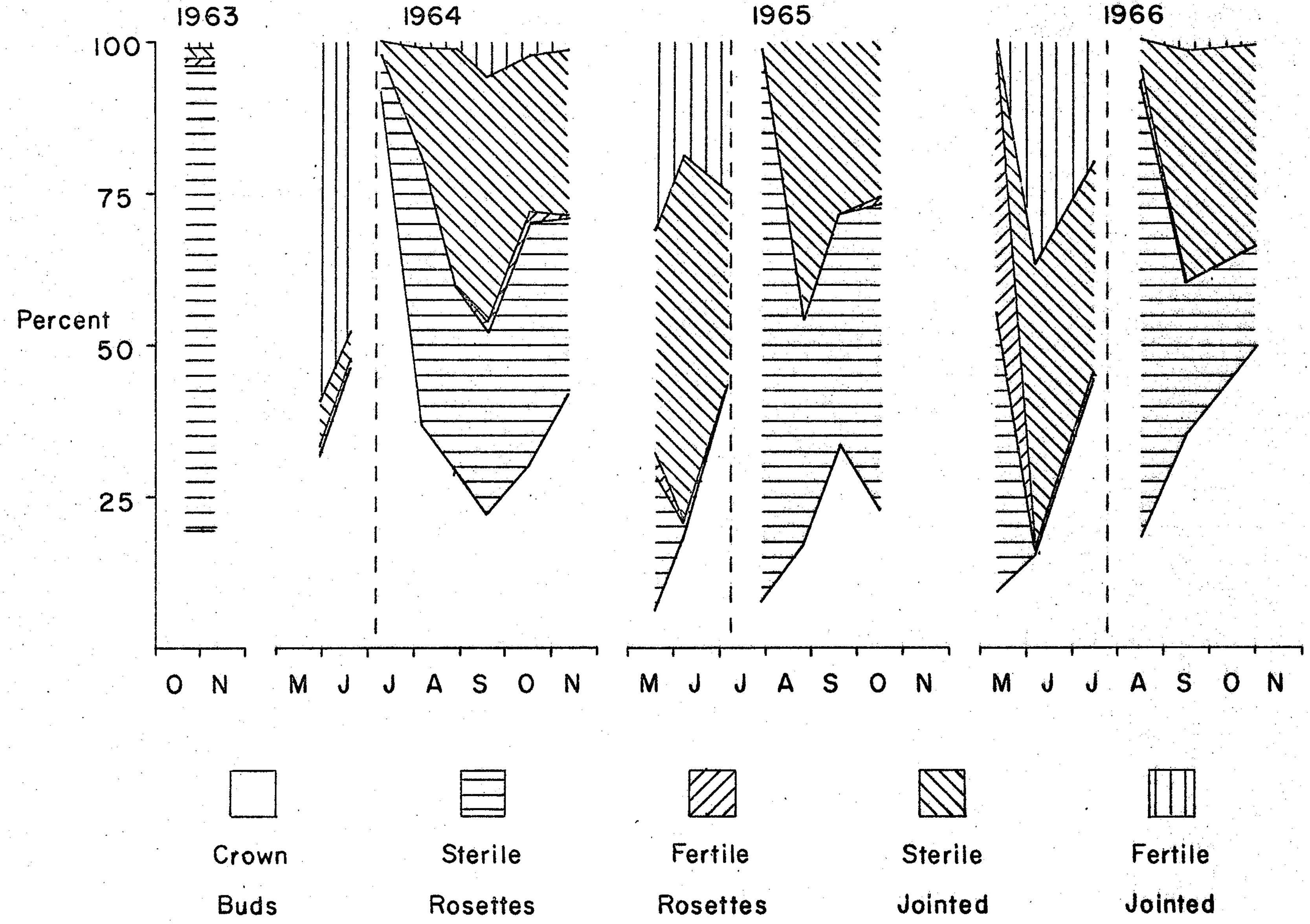
Relative proportions of the five tiller types in bromegrass grown for hay on a non-fertilized area



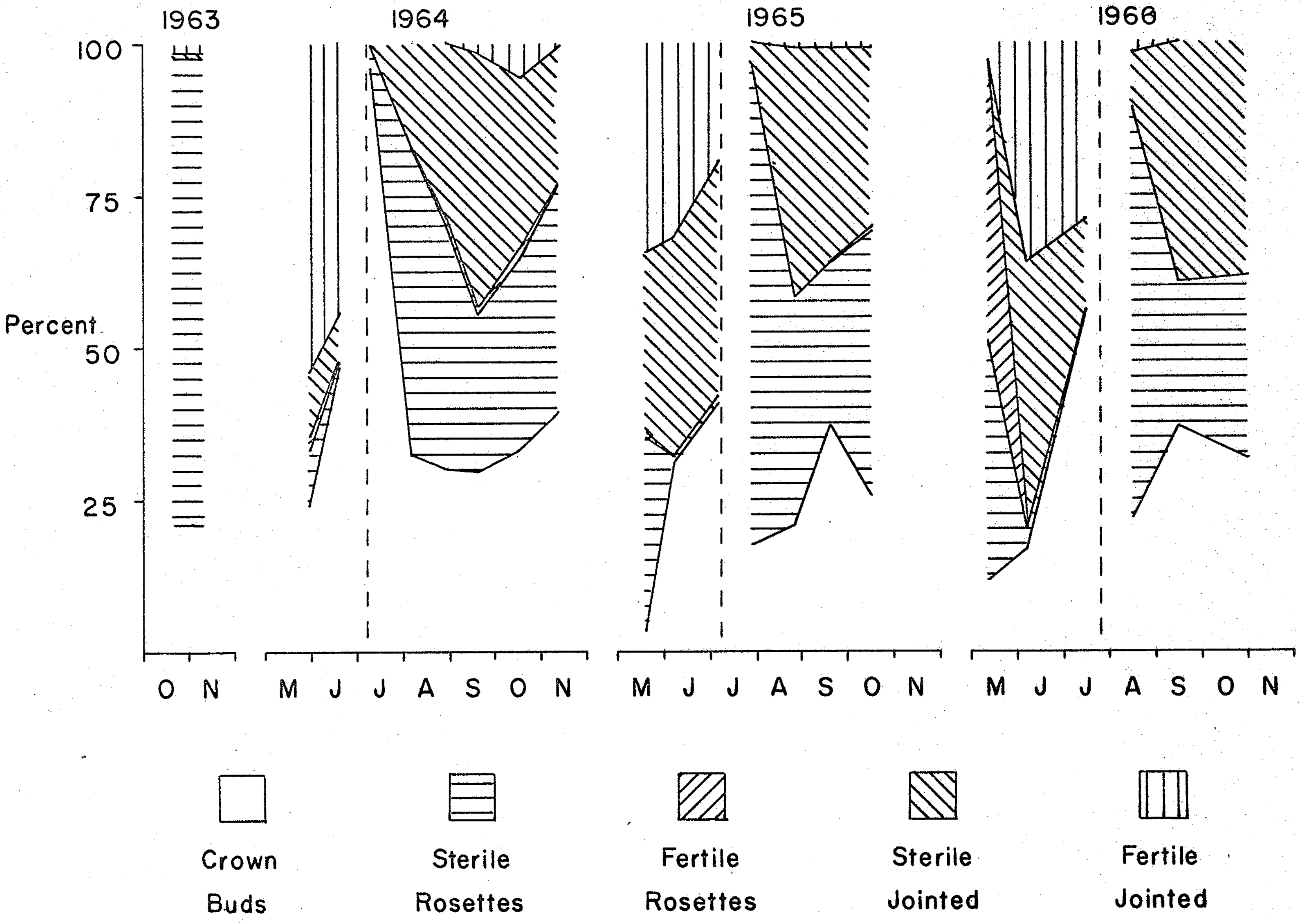
Relative proportions of the five tiller types in bromegrass grown for hay
on an area fertilized in spring



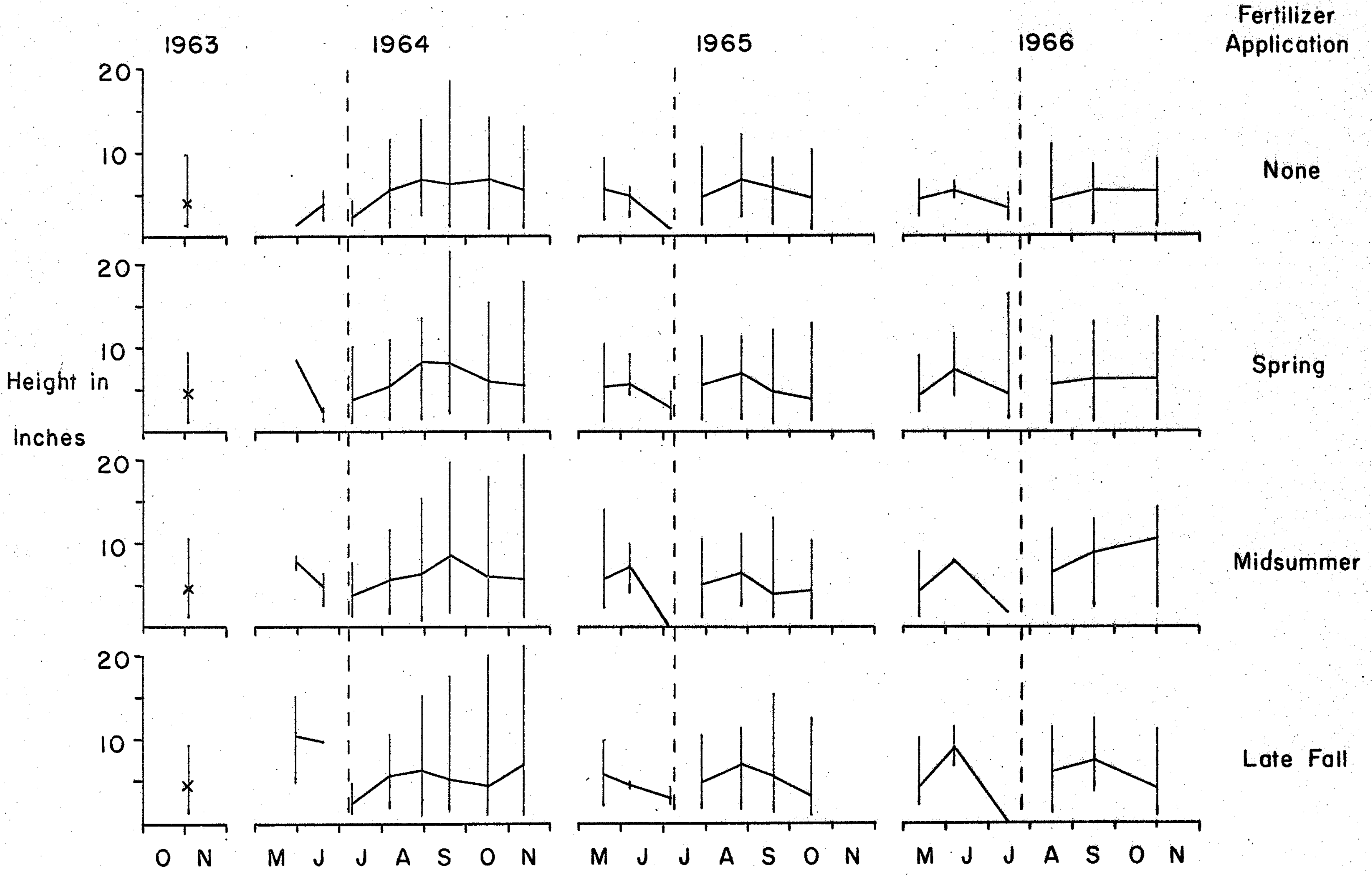
Relative proportions of the five tiller types in bromegrass grown for hay
on an area fertilized in midsummer



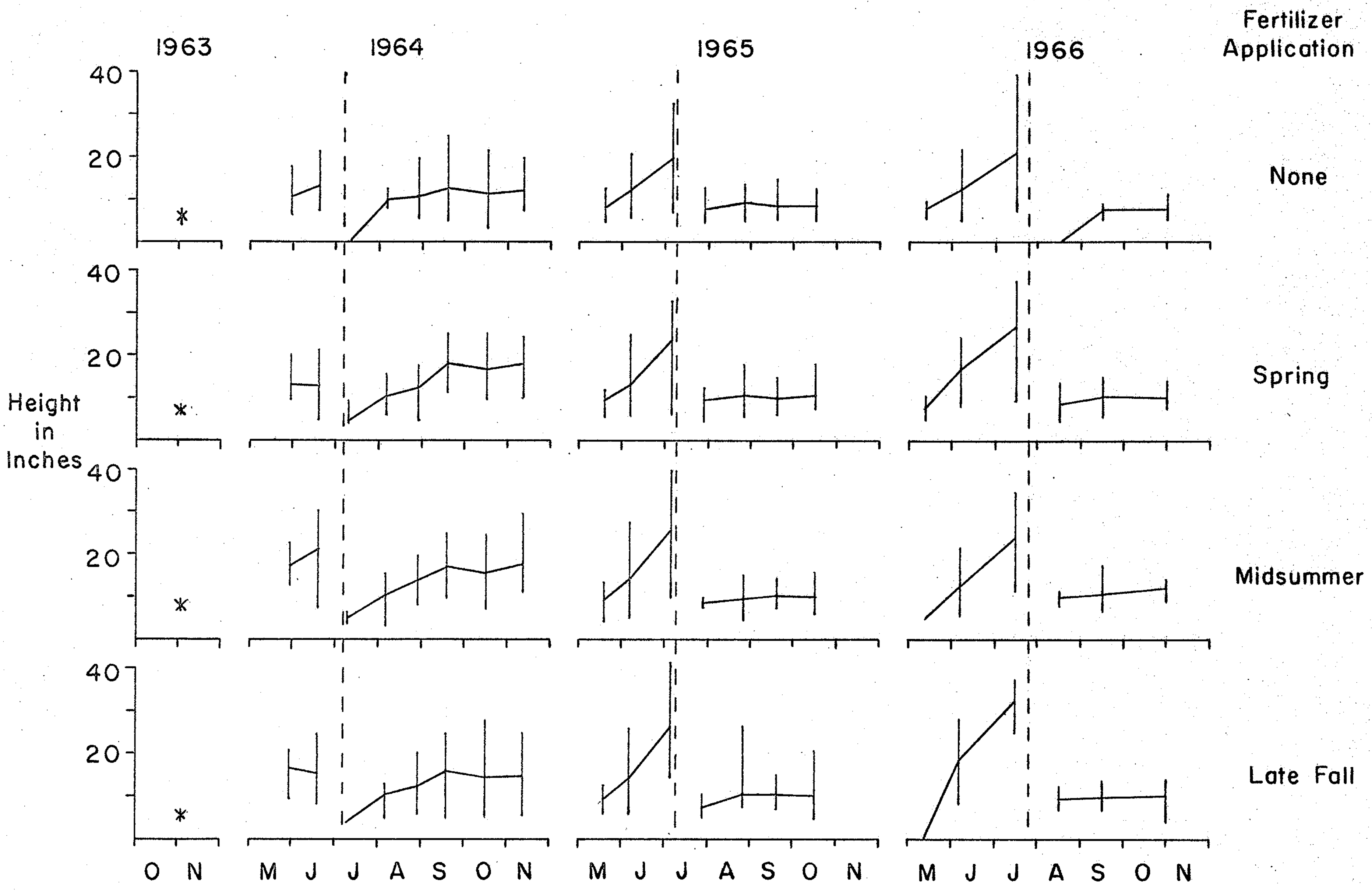
Relative proportions of the five tiller types in bromegrass grown for hay on an area fertilized in late fall



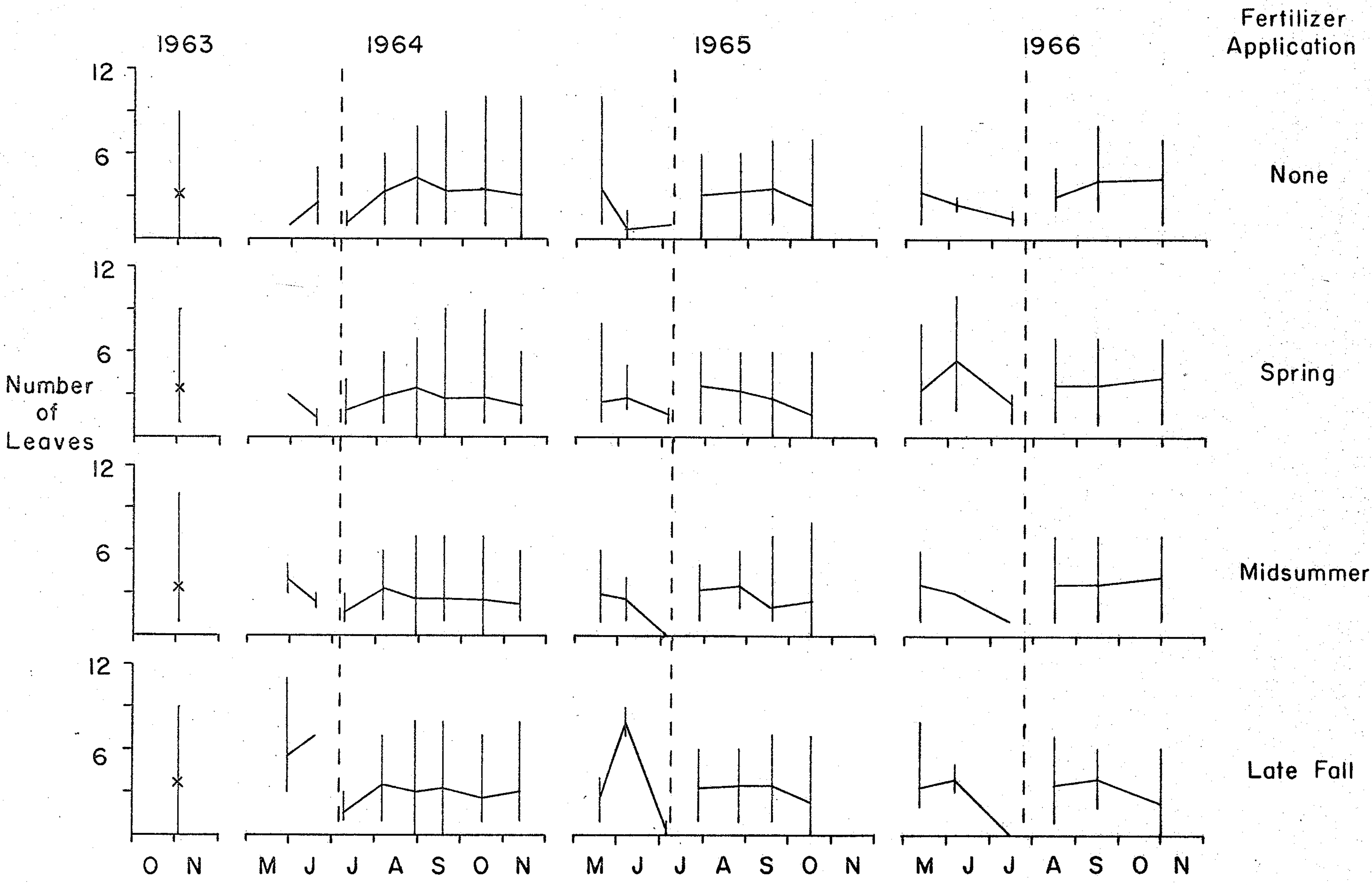
Height of sterile rosette tillers from bromegrass grown for hay



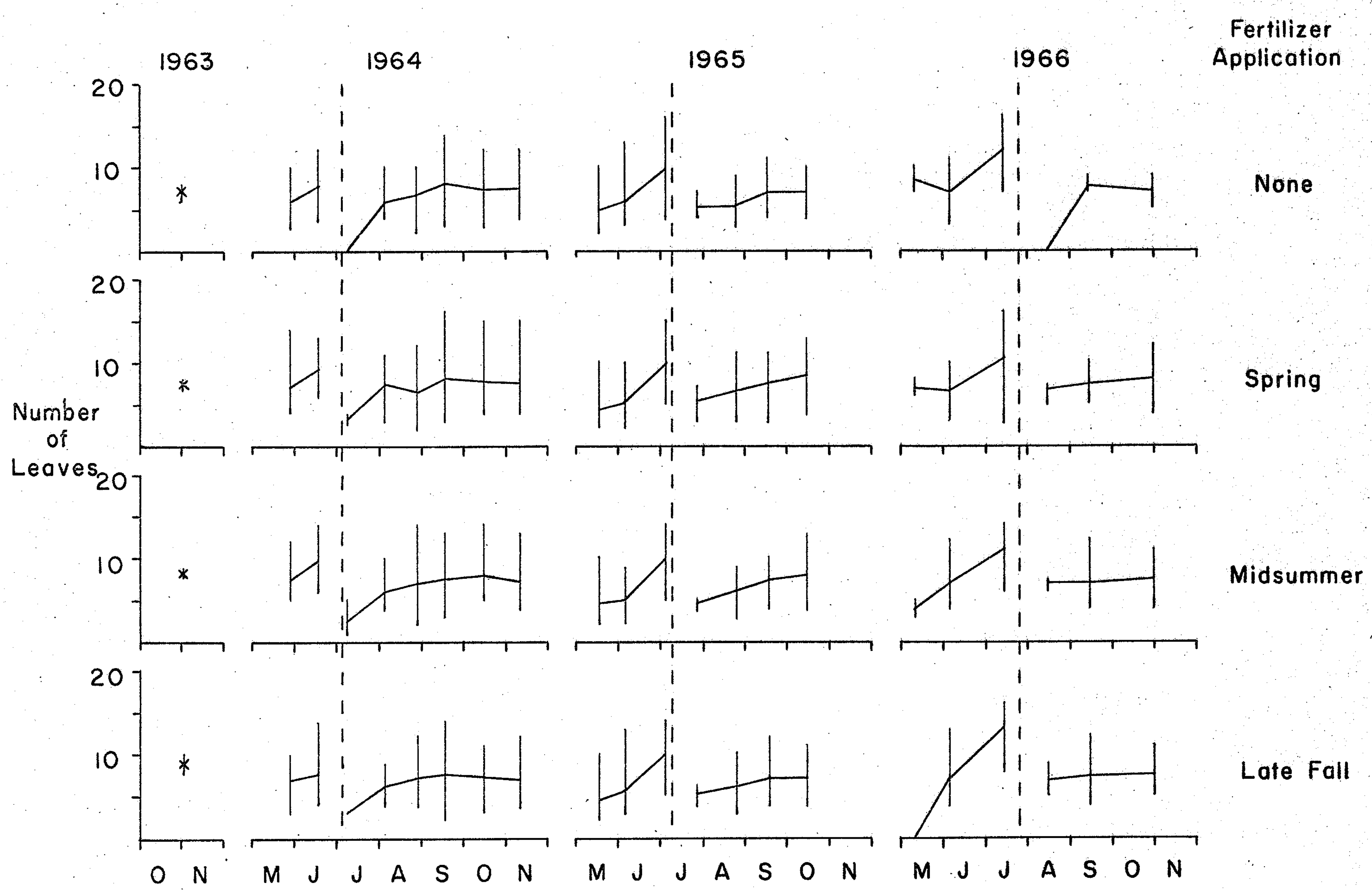
Height of sterile jointed tillers from bromegrass grown for hay



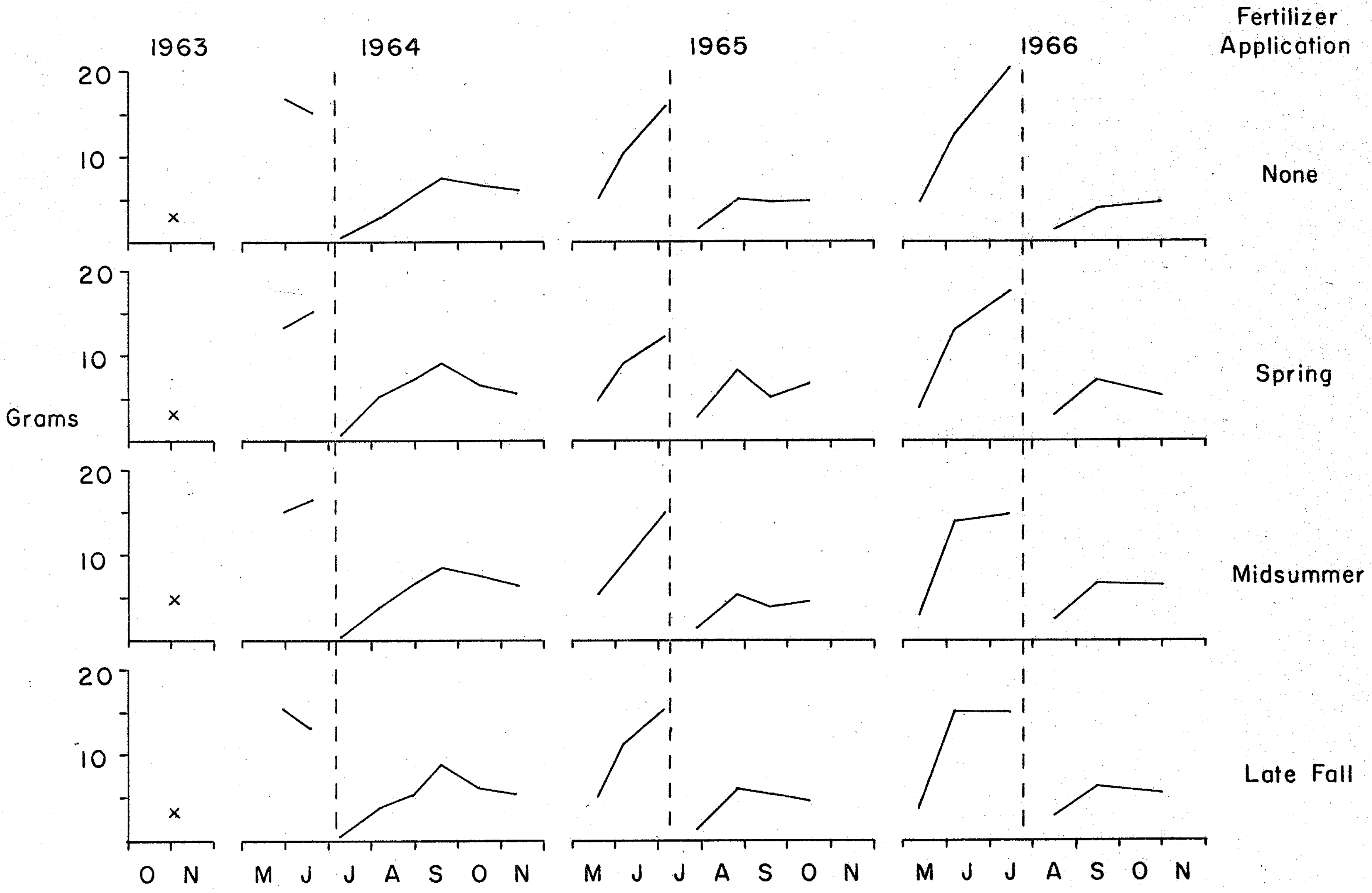
Number of leaves on sterile rosette tillers from bromegrass grown for hay



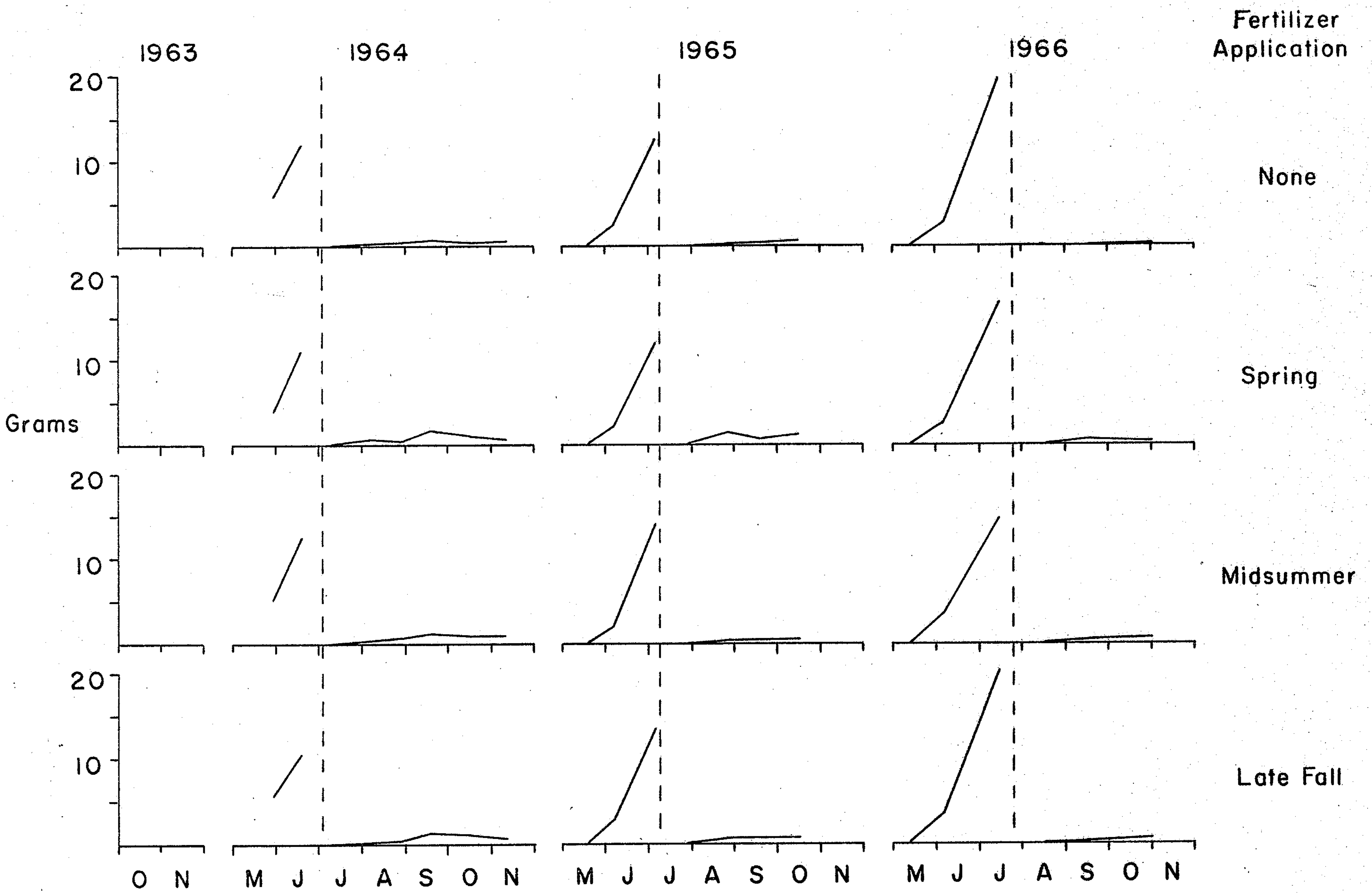
Number of leaves on sterile jointed tillers from bromegrass grown for hay



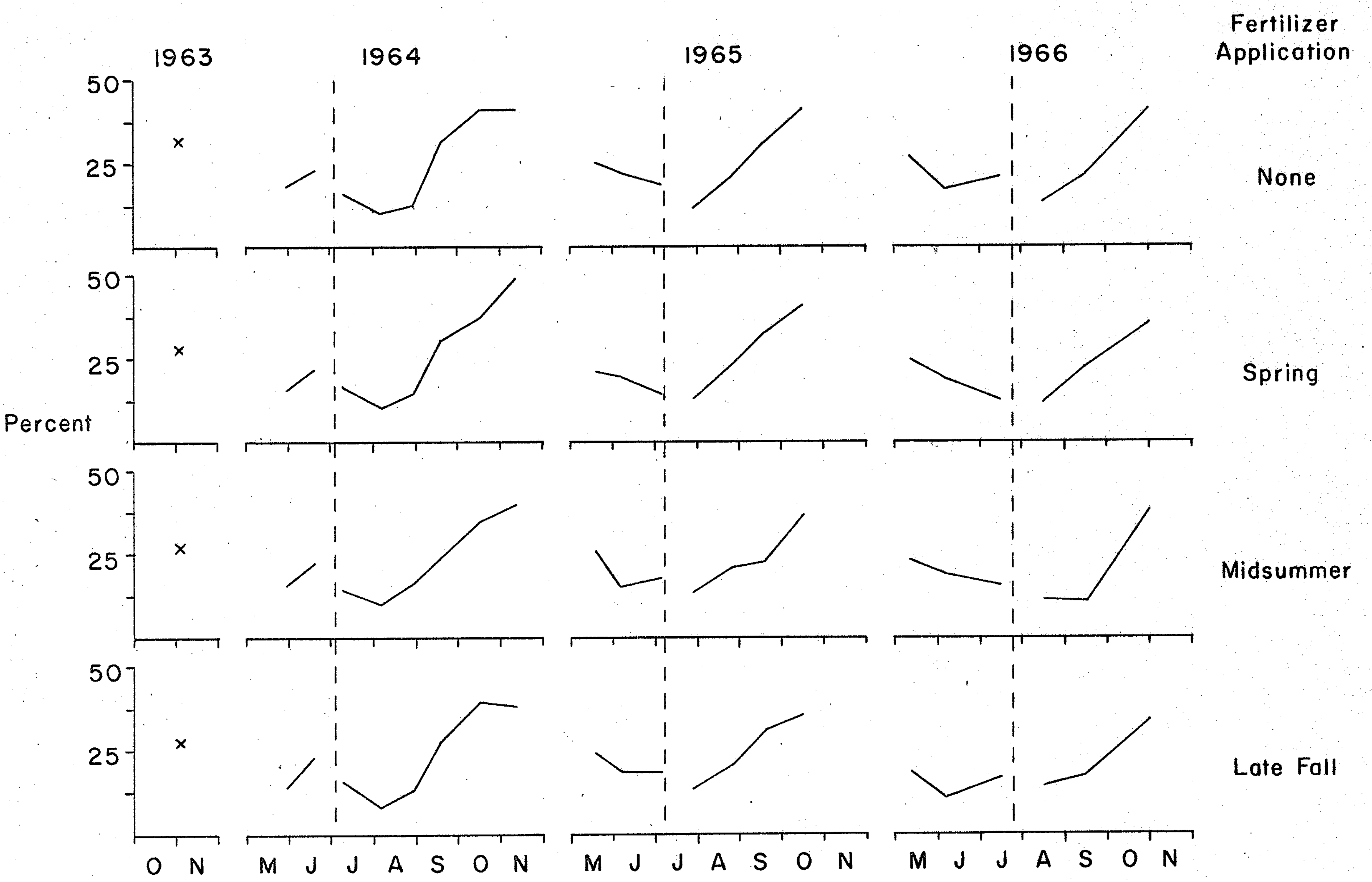
Dry weight of leaves on a fifty tiller sample from bromegrass grown for hay



Dry weight of stems of a fifty tiller sample from bromegrass grown for hay



Acid soluble carbohydrate percentage content of rhizomes of bromegrass grown for hay



1964, 1965, and 1966 were respectively 1.7 tons, 2.3 tons and 2.1 tons per acre for the non-fertilized plots and 2.3 tons, 3.4 tons and 3.0 tons per acre for the fertilized areas. Yields were highest from fall fertilized plots. Undoubtedly, part of the higher first cut yield in 1965 compared to 1964 was due to the later cutting date. However, other factors were probably operating, as lower yields in 1966 were obtained from a harvest taken a week later than in 1965.

The second forage harvest of each year produced its highest dry matter yields in 1964: 1.0, 1.8 and 1.5 tons per acre from check, spring, and summer or fall fertilized plots respectively. In 1965, the same treatments produced 0.8 tons, 1.7 tons and 1.2 tons per acre. In 1966, plots fertilized in summer produced 0.9 tons per acre from the second cut compared to 0.6 tons from plots fertilized in spring and 0.3 tons from the check and fall fertilized plots.

In both spring and summer cuts, dry matter yield from unfertilized areas was lower than from fertilized areas, though not significantly so in 1964 or 1965. In the second harvest of 1966, plots fertilized in mid-summer produced significantly ($p < 0.05$) more dry matter than plots fertilized in spring, and both yielded more than plots fertilized in late fall or check plots ($p < 0.05$) (Appendices 19, 20).

It should also be noted that an interval of two months of growth between the application of fertilizer and the time of cutting produced an increase in yield from the treated area above the increase

Table 8

The influence of fertilizer on dry matter production from "Lincoln" bromegrass cut for forage twice per year at Winnipeg

Year	Time of fertilizer application	Dry matter production (tons/acre)			Yearly average
		First cut	Second cut	Total	
1964	Non-fertilized	1.7 #	1.0	2.7	3.6
	Spring	2.2	1.8	4.0	
	Midsummer	2.5	1.5	4.0	
	Late Fall	2.5	1.4	3.9	
1965	Non-fertilized	2.3	0.8	3.1	4.3
	Spring	3.2	1.7	4.9	
	Midsummer	3.1	1.2	4.3	
	Late Fall	3.6	1.1	4.7	
1966	Non-fertilized	2.1	0.3	2.4	3.3
	Spring	2.8	0.6	3.4	
	Midsummer	2.9	0.9	3.8	
	Late Fall	3.1	0.4	3.5	
Three year total	Non-fertilized	6.1	2.1	8.2	
	Spring	8.2	4.1	12.3	
	Midsummer	8.5	3.6	12.1	
	Late Fall	9.2	2.9	12.1	

Yields are the average of four replicates

caused by application of fertilizer at other times of the year. In Scotland, Moon (50) found that fertilizer applied at least three weeks before harvesting the forage increased production, but that if the interval was less than this, results were erratic in dry years. It is suggested that, as observed the interval of growth required for the same effect in Manitoba would generally be longer because of the drier conditions in comparison to Scotland.

The first cut produced substantially higher amounts of dry matter than the second cut, and this difference became more pronounced as the brome stand aged. Spring applications of fertilizer minimized the yield differences between the two cuts while fertilizer applications in late fall accentuated the differences (Table 8). However, production over the total period was not markedly influenced by the time of fertilizer application; all applications increased dry matter yields by about 50% (Table 8) with significantly ($p < 0.01$) higher average production in 1965 than in 1964 and 1966 (Appendix 21).

Protein production for each harvest, each year and the three year total production is presented in Table 9 as pounds of crude protein per acre. A number of plot samples from the second cut in 1964 were lost before they could be analysed for protein content. Protein yields for these plots were estimated from their dry weight and the average protein content of the plot samples which remained. Correlation between the dry weight and the protein content of samples which were accounted for was 0.99, so the use of estimates for missing

Table 9

The influence of fertilizer on crude protein production by "Lincoln" bromegrass cut for forage twice per year at Winnipeg

Year	Time of fertilizer application	Crude protein production (lbs./acre) First cut	Second cut	Total	Yearly average
1964	Non-fertilized	414[1]	232[2]	646	967
	Spring	650	417[2]	1067	
	Midsummer	737	347[2]	1084	
	Late Fall	755	316[2]	1071	
1965	Non-fertilized	385	138	523	797
	Spring	632	276	908	
	Midsummer	559	283	842	
	Late Fall	682	232	914	
1966	Non-fertilized	290	40	330	589
	Spring	635	87	722	
	Midsummer	428	203	631	
	Late Fall	588	83	671	
Three year total	Non-fertilized	1089	410	1499	
	Spring	1917	780	2697	
	Midsummer	1724	833	2557	
	Late Fall	2025	631	2656	

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[1] Yields are the average of four replicates

[2] Protein estimated from dry weight

protein values will have introduced little error.

Protein production per acre from the first cut decreased in the non-fertilized areas from 414 lbs. in 1964 to 290 lbs. in 1966, in the areas fertilized in mid-summer from 737 lbs. to 428 lbs. and in the areas fertilized in late fall from 755 lbs. to 588 lbs. over the same period. Yield from plots fertilized in spring remained constant at 630 - 650 lbs. per acre at the initial cut of each harvest year (Table 9).

Protein production from the second cut showed precipitous declines during the course of the experiment in each of the check, spring fertilization and fall fertilization treatments. The protein production per acre of check plots in summer fell from 232 lbs. in 1964 to 40 lbs. in 1966. Summer and fall fertilization treatments produced 1.5 - 2 times the protein of the check plots at each second harvest. Protein produced from the second cut of the plots fertilized in mid-summer fell less rapidly from 347 lbs. per acre in 1964 to 203 lbs. per acre in 1966 (Table 9).

Average protein production was highest in 1964 and lowest in 1966. Yearly differences were significant ($p < 0.05$) (Appendix 24). The maximum production of protein in 1964 with a dry matter production significantly less than in 1965 (Appendix 21) was probably caused largely by the earlier cutting dates of both harvests, and demonstrates that higher quality forage is produced by cutting before the grass stem has matured and become high in fibre and low in protein.

At all harvest dates, non-fertilized areas produced less protein than the fertilized areas, but not significantly so in 1964 and 1965. In 1966, the fertilizer treatments doubled protein yield from the first cut and the summer fertilizer application produced significantly ($p<0.01$) more protein in the second cut than did the other treatments (Appendices 22, 23). This last difference was probably caused by the very late date of the second harvest permitting the summer application of fertilizer to exert a large effect on growth.

Over the three year period, the application of 185 lbs. per acre of 27-14-0 fertilizer almost doubled crude protein production. Slight yield differences were in favour of late fall or spring applications (Table 9) but were not significant ($p>0.05$).

The growth patterns of the various tiller stages are presented in Figures 25 to 35 and Appendices 25 to 28. The plots were trimmed to three inches on August 23, 1963. This removed the jointed tillers at a time when daylength had shortened to a value marginal for internode elongation. By the beginning of November, 10% of the tillers present had elongated internodes (Figures 25, 26, 27, 28). It is likely that most of these were present at the time the plots were trimmed but had their growing points less than the three inches above ground level at which the rotary mower was set. The sterile rosette tiller stage contained 65% of the tillers, and 20% of the tillers were crown buds. The remainder of the tiller population was at the fertile rosette stage, resulting in 5% fertile tillers in the population (Figures 25, 26, 27, 28).

At the end of the 1963 growing season, the crown buds averaged 0.75 inches in length and had 6 leaf initials (Appendix 25). The sterile rosettes had an average length of 4.5 inches and an average leaf number of 3.5, but heights ranged from 1 to 14 inches and leaf numbers from 0 to 9 (Figures 29, 31). The sterile jointed tillers averaged 9 inches in height with 9 leaves and 7 extended internodes. Their heights ranged from 6 to 14 inches, leaf numbers ranged from 6 to 12 and elongated internodes ranged from 5 to 11 (Figures 30, 32). Obviously some growth took place between the end of August and the beginning of November. Also, the considerable overlap in the ranges of the tiller characteristics suggests that tiller initiation and growth were a continuous process as suggested by Lamp (36) and that the trimming of the plots at the end of August did not interrupt this process.

Tiller growth in early spring followed a similar course in each of the three harvest years and was very similar to the growth pattern described previously as taking place in the plots harvested for seed or for hay. In 1964, tiller samples were taken from plots only once before the first forage cut on June 5. At that time, crown buds constituted 35% to 40% of the tiller population except in the plots fertilized the previous fall, where only 24% of the tillers were at the crown bud stage. The rest of the tiller population was made up of jointed tillers, 10% sterile and 50% to 55% fertile (Figures 25, 26, 27). Plots fertilized the previous fall were again the exceptions with 65% of the tillers at the fertile jointed stage (Figure 28). At the time of the first tiller sampling in 1964, few tillers were at the rosette stage of growth (Figures 25, 26, 27, 28).

In both 1965 and 1966, tiller samples were taken twice before the plots were harvested for the first time. In both years, an increase in crown bud representation from 10% to 30% took place between the two sampling dates. In both years, plots fertilized the previous summer had fewest crown buds; only 20% at the time of the second sampling. At the first sampling date in 1965 the rosette stages of tiller development formed 25% to 35% of the tiller population, and the jointed tillers, 50% to 60%. At the second sampling date, the rosette stages were absent, and the jointed tillers formed 60% to 70% of the tiller population. The rosette stages of tiller growth predominated at the first 1966 sampling date, containing 90% to 100% of the tillers. By the time of the second sampling date, the rosette stages had been replaced by jointed tillers which formed 60% to 70% of the tiller population (Figures 25, 26, 27, 28). Thus, at the time of the first cutting, in all harvest years, all plots consisted of jointed tillers which were harvested, and crown buds, which represented the potential regrowth.

By the time of the first harvest cut, sterile jointed tillers from fertilized plots were approaching 20 inches in height, had 8 leaves and 4 to 5 leaf initials, and had extended 6 internodes which raised the growing point 10 inches above the ground. Sterile jointed tillers from non-fertilized plots were similar in most respects but averaged only 15 inches in height and had raised their growing points to 6 inches above ground level (Figures 30, 32; Appendix 26). Fertile jointed tillers were 30 inches tall, had 9 leaves (7 leaves in 1965), and had elongated 6 internodes (Figures 9, 12; Appendix 10). Flowering heads were emerging in 1964 and had emerged in 1965 and 1966 at harvest time. Fertile tillers from non-fertilized areas were slightly shorter than those from fertilized areas in 1966.

Leaf dry matter production from the 50 tiller samples taken just before harvest in 1964 was 15 grams from fertilized plots and 12 grams from non-fertilized plots. In 1965 and 1966, leaf dry matter from 50 tiller samples was between 10 and 14 grams, with non-fertilized tiller production being the lower (Figure 33). Stem production showed the same trends, 4 to 6 grams in 1964 and 2 to 4 grams in 1965 and 1966, with non-fertilized tillers producing the lowest dry matter weights (Figure 34).

By the time of the first harvest, a differentiation between jointed tillers from fertilized areas and from non-fertilized areas was evident in tiller height and dry weight. These differences were reflected in the amount of dry matter harvested from the plots (Table 8). Differences in the ratio, jointed tillers/crown buds between fertilizer treatments within years, and year to year differences in the ratio appeared to have no relationship with dry matter yield at the first harvest. The year of highest dry matter production in the spring of 1965, also was the year of the lowest ratio, jointed tillers/crown buds. The converse was not true, for the year of lowest dry matter production in the spring of 1964 did not have the highest ratio. It is concluded that dry matter yield is correlated positively with the size of harvested tillers but not with the proportion of such tillers in the population. Probably, the absolute number of harvested tillers per unit area affected yield. In the final year of the experiment, it was clear that a larger area of turf had to be taken from non-fertilized plots than from fertilized plots to obtain fifty tillers. This supports Watkins' conclusions (70) that nitrogenous fertilizer increased the tiller density per unit area.

After the first harvest, the crown buds grew rapidly and two weeks later, when the first tiller samples after harvest were taken, the proportion of tillers with green leaves in thepopulation was between 70% and 95%. At this time, jointing commenced, and shortly after an increase in crown bud production took place (Figures 25, 26, 27, 28). Thus, the tiller pattern changed rapidly during July in all harvest years. The pattern differed in detail between the years. This was probably caused in part by the relatively late second cuts in 1965 and 1966 in comparison to 1964 (Table 2).

In 1964, jointing of the regrowth tillers raised the growing points of most of them above ground level by early July. The spring application of fertilizer induced the most rapid growth. On July 8th, 80% of the tillers had jointed, leaving only 5% at the rosette stage (Figure 26). The slowest growth occurred in the non-fertilized plots: only 65% of the tillers had jointed by July 8th and 20% remained at the rosette stage (Figure 25). Areas given fertilizer in mid-summer or late fall developed a proportion of jointed tillers intermediate between the two extremes (Figures 27, 28). The heights of the jointed tillers on July 8 also showed fertilizer effects. The mean height of jointed tillers from plots fertilized in spring was 16 inches; of similar tillers from non-fertilized plots it was 12 inches, and of tillers from other treatments, 14 inches (Figure 30). The range of heights was not affected by fertilizer and was 6 inches to 22 inches (Figure 30). Other jointed tiller parts were not affected by fertilizer. On July 8th, all treatments had jointed tillers with an average of 5 leaves (Figure 32), 5 leaf initials, and 4 extended internodes (Appendix 26).

During late June of 1964, crown bud replacement was slow. They had increased from 8% to 12% (Figures 25, 27, 28) by July 8th except in the plots receiving the spring application of fertilizer where the crown bud proportion of the population remained at 6% (Figure 26). A rapid drop in average crown bud length from 1.3 to 0.5 inches took place over the same period, and the maximum length also dropped from 2 inches to 1.25 inches (Appendix 25). It is suggested that new crown bud production during this time was negligible.

During July of 1964, new crown buds were produced in large numbers and by the time of the second harvest in mid-August, crown buds accounted for 52% of the tillers in the plots. Also, by the second harvest, the remainder of the rosette tillers had jointed so that 45% of the tiller population consisted of sterile jointed tillers (Figures 25, 26, 27, 28). No differences in the jointed tiller/crown bud ratios were present between fertilizer treatments at the second harvest, but differences in jointed tiller heights were the same as at July 8th, the average heights having increased only one inch in the interval. However, the green leaves had increased to 9 on the tillers from fertilized plots and to 8 on tillers from non-fertilized plots, and the range of leaves had also increased and was 2 to 13 with little difference between fertilizer treatments (Figure 32). The number of extended internodes per jointed tiller at the time of the second harvest was 8.5 in fertilized plots and 7.5 in non-fertilized plots (Appendix 26). Clearly, there was no leaf accumulation by unextended internodes at soil level as occurred in fall and early spring when conditions were unfavourable for internode elongation.

After the first cut in 1965, regrowth took a similar course to the one it had taken in 1964, except at a later date due to the 1965 first cut being made two weeks later than in 1964 (Table 2). By the end of July in 1965, 60% to 75% of the tiller population had jointed (Figures 25, 26, 27, 28). Unlike the 1964 growth, in 1965, plots receiving a fall application of fertilizer jointed most rapidly. Rosette tillers made up 10% of the tiller population in plots fertilized in spring or fall, 20% in non-fertilized plots, and 30% in plots fertilized in summer.

The crown bud portion of the tiller population also showed considerable differences between treatments. During July of 1965, the proportion of crown buds in check plots and plots fertilized in summer remained constant at 22% and 10% respectively. In plots fertilized in spring, the crown bud proportion rose from 10% to 26% and in plots fertilized in fall, fell from 22% to 12% (Figures 25, 26, 27, 28). Apparently, the spring application of fertilizer caused a rapid replacement of crown buds in July of 1965. An increase in crown buds from 10% of the tiller population at the end of July to 30% at the end of August was attributed to the summer application of fertilizer. Crown buds in the check plots and the plots fertilized in fall increased only slowly during the first part of August in 1965, and more rapidly in late August and early September. During early September, crown buds in the plots fertilized in spring and summer declined in numbers. At the time of the second harvest of 1965,crown buds made up 40% of the tiller population of plots fertilized in the fall, 30% in check plots and plots fertilized in spring, and 20% in the summer fertilized plots (Figures 25, 26, 27, 28).

A reduction in the average crown bud length as occurred in the summer of 1964, also took place in July and early August of 1965. Starting in late August, a marked increase in crown bud activity occurred resulting in an increase in average height to 0.75 inches and a marked increase in maximum height from 1 to 2 inches (Appendix 25). At the same time, the proportion of rosette tillers increased from near zero at the end of August to 20% by the middle of September for all treatments except that of summer fertilization where the proportion of rosette tillers increased to 50% (Figures 25, 26, 27, 28).

Also, during the last week of August and the first two weeks of September, the average height of rosette tillers from plots fertilized in summer decreased from 8 inches to 4 inches, and the average height of rosettes from other plots decreased from 6 inches to 2.5 inches (Figure 29). The number of green leaves on rosette tillers declined from 3 to 2 (Figure 31) and leaf initials increased from 3.5 to 6.5 during the same interval.

As a result of the increase in crown bud and rosette tiller numbers in the late summer of 1965, the proportions of jointed tillers in the population at the time of the second harvest were 55% in the plots fertilized in spring, 45% in check plots and plots fertilized in fall, and 25% in the plots fertilized in summer (Figures 25, 26, 27, 28). There was no evidence that the decrease of jointed tiller percentage representation in the population was caused by an absolute decrease. As in 1964, the apparent loss of jointed tillers was probably caused by increases in crown buds and, particularly in 1965, by increases in rosette tillers.

During the 1965 summer growth period, the height of the jointed tillers was notably influenced by fertilization in spring. By the time of the second harvest, jointed tillers from these plots averaged 16 inches in height with a range of 9 to 29 inches. The other treatments showed similar effects: jointed tillers were 11 inches tall with a range of 5 to 20 inches. Leaves, leaf initials and the number of extended internodes were not affected differentially by the various times of fertilizer application. Jointed tillers had on average 8.5 leaves (Figure 32), 4 leaf initials and 8 elongated internodes (Appendix 26) at the time of the second cut on Sept. 20, 1965. The height above ground of the growing points of jointed tillers was affected in the same way as the total tiller length. Growing points of jointed tillers from plots fertilized in spring averaged 8 inches above ground level; growing points of tillers from check plots and other times of fertilization averaged only 5 inches above soil level. In all plots, the majority of the jointed tillers were removed by the harvest cut.

In 1966, regrowth after the first forage cut again proceeded most quickly to the jointed tiller stage in the plots fertilized in spring. By mid-August, 55% of the tillers in the plots fertilized in spring were at the jointing stage, compared to 45% in check plots and fall fertilized plots, and only 30% in plots fertilized in summer. Rosette tillers showed a converse relationship, having 10% rosette tillers in the plots fertilized in spring, 25% in plots fertilized in fall, and in check plots, and 30% in plots fertilized in summer (Figures 25, 26, 27, 28).

Crown buds in the fertilized areas showed very similar increases from 5% to 10% two weeks after the first forage cut to 30% to 35% by the middle of August. The non-fertilized area had 20% crowm buds two weeks after the first cut and this increased only to 25% by mid-August and to 33% by the end of September. By this time, crown buds in plots fertilized in spring had increased to 40%, in plots fertilized in fall had remained at 30%, and in plots fertilized in summer had fallen to 20% (Figures 25, 26, 27, 28).

Clearly, the tillers in the non-fertilized plots started regrowth more slowly than in the fertilized areas. Also, it appears that the spring application of fertilizer caused an increase in crown bud production in late August, and the summer application caused an increase in jointed tiller production at the same time (Figures 25, 26, 27, 28). These two effects are hard to reconcile. However, if the effect of the summer fertilizer application in 1966 is considered the same as in 1965, except for affecting tiller increase one growth stage later, and if a later spring application of fertilizer in 1966 than in 1965 affected crown bud production an equal interval later, it can be seen that the differences between regrowth in 1965 and in 1966 are not great.

The effect of the different fertilizer treatments on the average length of the crown buds was consistent with the supposition that its application would increase the rate of growth. Two weeks after the first forage cut in 1966, the non-fertilized plots had the longest crown buds, 0.65 inch long, presumably because of faster regrowth in the fertilized plots (Appendix 25). By mid-August, all plots had crown bud samples of 0.5 inch long. During late August and September, the summer application of fertilizer resulted in a slower increase in height of crown buds from that treatment (Appendix 25) because, it is suggested, the fertilizer increased the growth rate, causing the longer crown buds to develop leaves, thus entering the rosette stage and leaving the shorter crown buds behind to lower the average height compared to crown buds in other treatments. Similarly, the larger rosette tillers in late August would joint, and so increase the proportion of the jointed tiller group at about the same rate as the crown bud group decreased.

The heights of the rosette tillers reached their maxima some time after the application of fertilizer to the plots. Non-fertilized plots produced tillers which increased in height throughout the period between forage cuts from 4.5 inches two weeks after the first cut to 6.5 inches before the second cut. The fall fertilized rosette tillers decreased in height over the same period from 6.5 inches to 4.5 inches: their average height had reached its maximum in the two weeks after the initial cut and jointing after that time affected a reduction in average height and representation of the class from then until jointing stopped at the end of August (Figure 29). The application of fertilizer in spring led to a maximum height in mid-August of 8 inches. The summer application of fertilizer at the end of July produced an increase in rosette tiller height from 6 inches in mid-August to 8 inches in mid-September (Figure 29). Green leaves on rosette tillers showed a similar behaviour to fertilizer as rosette height, but diverged little from 3 leaves for most of the summer of 1966 (Figure 31).

After the tillers jointed, faster growth occurred in fertilized plots. By mid-August, jointed tillers averaged 12 inches in height on fertilized plots and only 9 inches in height on non-fertilized plots (Figure 30). This relationship was maintained until the second forage cut, only tillers on the plots receiving fertilizer in summer increased in height after the middle of August.

Jointed tillers were larger in non-fertilized than in fertilized plots two weeks after the first forage cut in 1966. Leaf count was 6.5 compared to 4 from other treatments (Figure 32), number of extended nodes was 5.5 compared to 3 for tillers from other treatments (Appendix 26), and their growing points averaged two inches above ground level compared to 0.5 inches for tillers from the fertilized plots. Apparently, the survival of some jointed tillers which had growing points less than three inches above ground level at the time of the first cut produced the above results.

By the time of the second cut at the end of September, jointed tillers from plots fertilized in spring or fall had produced 8.5 leaves on average, compared to 7.5 on tillers from check plots and plots fertilized in summer (Figure 32). Corresponding means for extended internodes were 7.5 and 6.5 (Appendix 26). However, the height above ground of the growing points of the jointed tillers was greater in plots fertilized in spring: 4.25 inches compared to 3 inches for other treatments.

When the second forage cut was taken in 1964 only jointed tillers were present in addition to the crown buds. In 1965 and 1966, substantial proportions of the tiller populations were at the rosette stage of growth. Only leaves were cut from the rosette tillers and the growing points remained with 3 to 4 inches of leaf.

Fifty tiller samples taken just before the second forage cut produced 6 to 7 grams of leaf dry matter in 1964 (Figure 33). Differences between fertilizer treatments were small but were in favour of fertilization in summer or fall. Stem production from the same samples was 3.5 grams from plots fertilized in spring and 2.5 grams from each of the other treatments (Figure 34). When stem and leaf dry matter production were added together, a distinct correlation appeared between dry matter of the fifty tiller samples and dry matter production from the forage harvest.

In 1965, nine grams of leaves and three grams of stem material were produced by 50 tillers from plots fertilized in spring, compared to 5 grams of leaf material and 1 gram of stem material produced by tillers given other treatments (Figures 33, 34). While the tiller size from plots fertilized in spring was clearly larger than on other treatments and could have accounted in part for the superior yield of those plots at the second forage cut, the relative equality of tiller size produced by the other treatments and the check is in contrast to the marked yield differences in plot forage production. Presumably, the density of tillers per unit area produced the variations in yield between the different fertilizer treatments.

During the summer of 1966, similar amounts of leaf material were produced per tiller as in 1964 (Figure 33), but much less stem material. The samples taken just before the second forage cut in 1966 produced less than one gram of stem material (Figure 34). This is surprising in view of the long growing period (Table 2) - even longer than in 1965, and the apparently adequate rainfall (Appendix 29). The material harvested at the second forage cut in 1966 was also lower in quantity (Table 8). Presumably, the tiller density per unit area was low at that time.

Leaf protein at all cutting dates was approximately 10% of dry weight. Slightly higher protein content at all sampling dates was evident in leaves from fertilized plots (Figure 33). In particular, the addition of fertilizer in the summer of 1966 prevented the usual steady fall in leaf protein level that occurred with all other treatments (Appendix 27).

Protein content of the stems generally remained at about half the level of the leaf protein. Again, in 1966, the addition of fertilizer in summer increased protein in the stems (Appendix 28). As little stem was present in the material harvested at the end of September, the higher protein content was of little advantage. It is notable that stem protein content at the time of the first harvest in 1964 was 15%, compared to 8% in 1965 and 10% in 1966 (Appendix 28). This difference could have caused the higher protein yield of 1964 from a smaller dry matter production. Treatment differences in 1964 were in favour of the plots fertilized in summer or fall, and protein yields from the first harvest in 1964 produced more protein from the plots fertilized at those times (Table 9).

Regrowth after the second harvest was extensive only in 1964, because of late cuts in 1965 and 1966. In 1964, crown buds in fertilized areas rapidly produced green leaves, and two weeks after the second harvest, only 10% of tillers in the fertilized plots were crown buds, the remainder being mainly rosette tillers. On the non-fertilized areas, crown buds constituted 20% of the tiller population two weeks after harvest and were reduced to 10% three weeks later. Although tillers in the non-fertilized plots grew more slowly immediately after harvest, by the end of the growing season, all plots contained similar proportions of crown buds (25%), rosette tillers (70%) and jointed tillers (5%) (Figures 25, 26, 27, 28). The few jointed tillers were probably too short to be cut off at the time of the second harvest.

The height of the rosette tillers showed a distinct fertility effect in the fall of 1964. Rapid growth from an average height of 4 inches resulted by the end of the growing season in an average height of 9 inches for rosette tillers in plots fertilized in summer and 7 inches for rosettes from other treatments (Figure 29). Heights of rosette tillers ranged from 1 inch to 14 inches from mid-September to the end of the growing season. A similar effect was present in the few jointed tillers present. Those from plots fertilized in summer had an average height of 13 inches, compared to 11 inches for jointed tillers from other treatments (Figure 30). Leaf numbers were not affected by the various times of fertilizer application and remained at 4 for rosette tillers and 6 for jointed tillers (Figures 31, 32).

After the initial production of rosette tillers from crown buds shortly after the second forage cut, little further development of crown buds took place until near the end of the growing season. This is made clear by the maximum length of the crown buds. In mid-September of 1964, the longest were 1.0 inch whereas in early November the longest were 1.75 inches, at which length they are usually growing rapidly (Appendix 25).

In 1965 and 1966, the late cuts apparently had little effect on tiller growth. In both years the relative proportions between the different treatments of rosette tillers showed little change from their positions before the second harvest. Increases in their numbers were probably due to the removal of the jointed tillers by the harvests (Figures 25, 26, 27, 28).

It is suggested that in 1964 a third harvest could have been made at about the time that the second cuts were made in 1965 and 1966. Yields would have been low, as fifty tiller samples produced only five grams of leaves and little stem (Figures 33, 34) but would have been high in protein (Appendix 27).

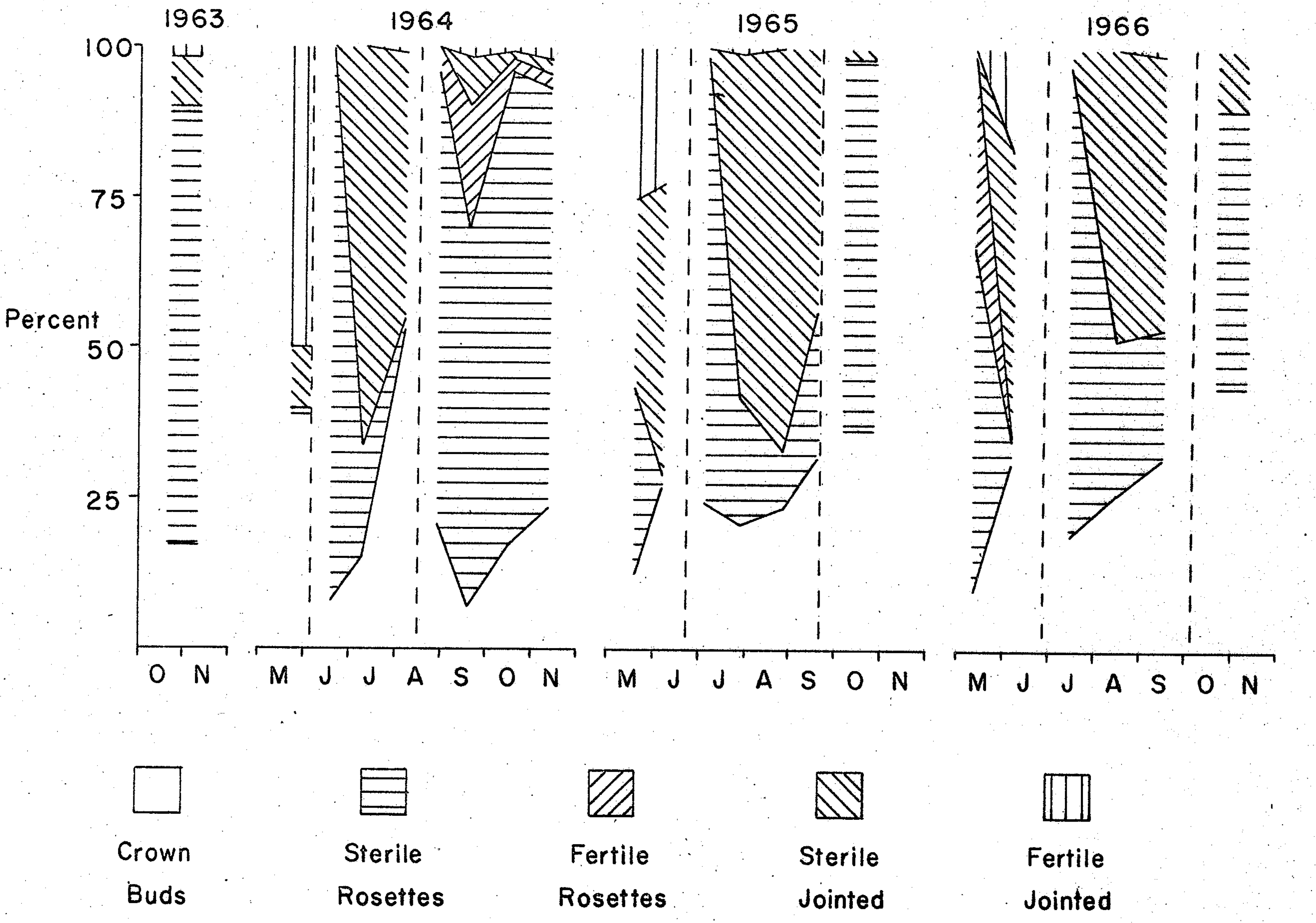
Soluble carbohydrate levels showed two low values corresponding to the two harvest cuts only in 1964, and in that year only in rhizomes from fertilized plots (Figure 35). The first low value, of 5% rhizome dry weight of carbohydrate occurred in mid-June, two weeks after the first forage cut, and occurred in all treatments. The second low value, of 10% occurred at the end of August, two weeks after the second harvest cut. Values from the non-fertilized plot were not affected and increased during that period from 12% to 15%. At the end of August in 1964, the carbohydrate level in the rhizomes subjected to the summer fertilization fell to 6%. During the remainder of the growing season, carbohydrate values increased rapidly to 37% by weight, although the carbohydrate level reached under summer fertilization lagged some 3% until November.

In 1965, only a slight dip in carbohydrate values at the 20% level occurred in early June under fertilization. The lowest values of 10% occurred in late July near the end of the period of rapid tiller regrowth and jointing. Carbohydrate levels again increased rapidly in fall to levels of 30% (Figure 35).

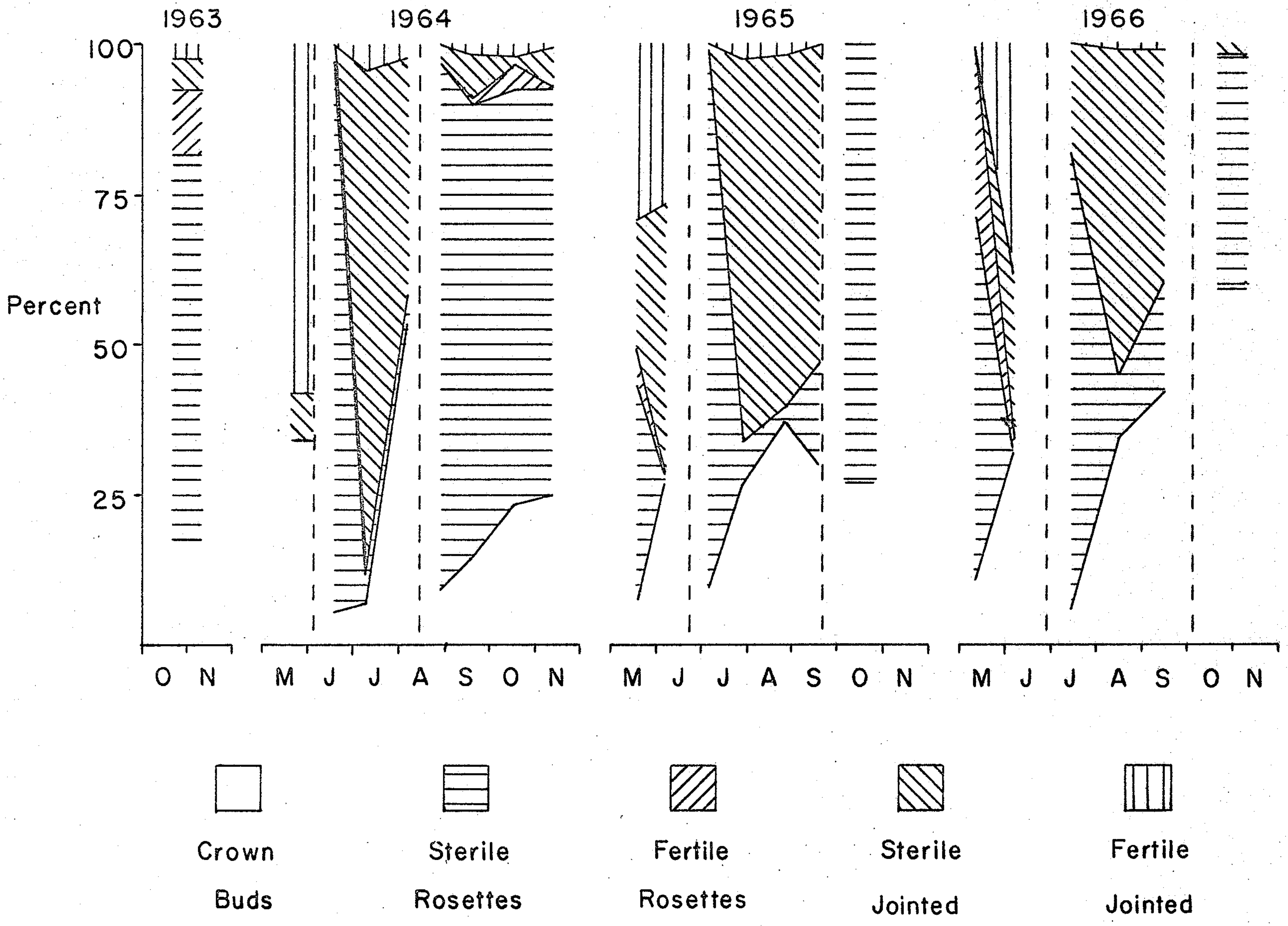
In 1966, perhaps in part because of more widely spaced sampling dates, less abrupt changes in carbohydrate values were measured. Values declined from 20% in early spring to 10% in July, and then increased again to 30% by the end of the growing season (Figure 35). In 1966, there appeared to be a definite trend towards a higher carbohydrate content in rhizomes grown without added fertilizer.

The cyclic reduction in carbohydrate content of the rhizomes is in accord with previous evidence that storage organs supply energy

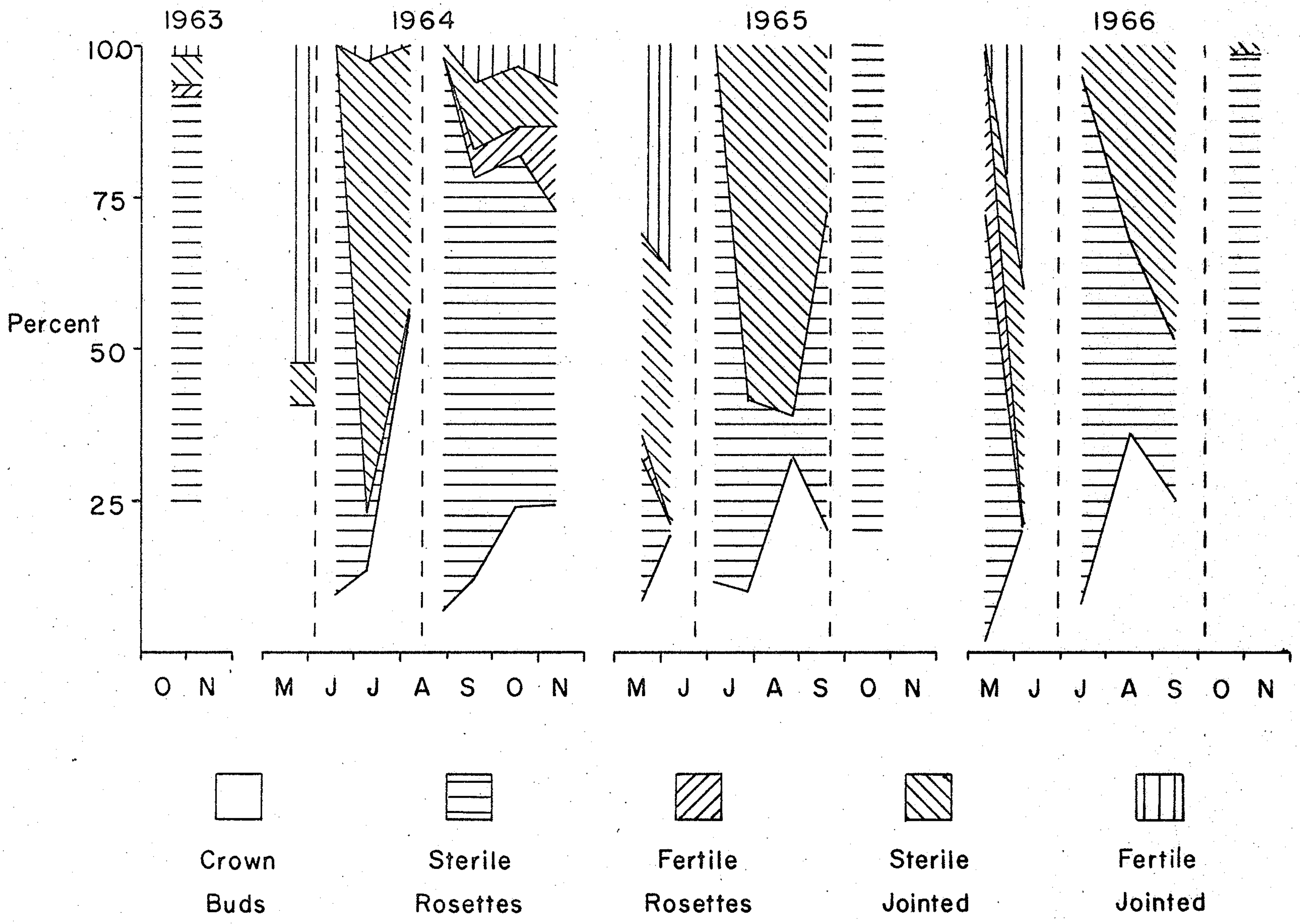
Relative proportions of the five tiller types in bromegrass grown on a non-fertilized area and cut for forage twice per year



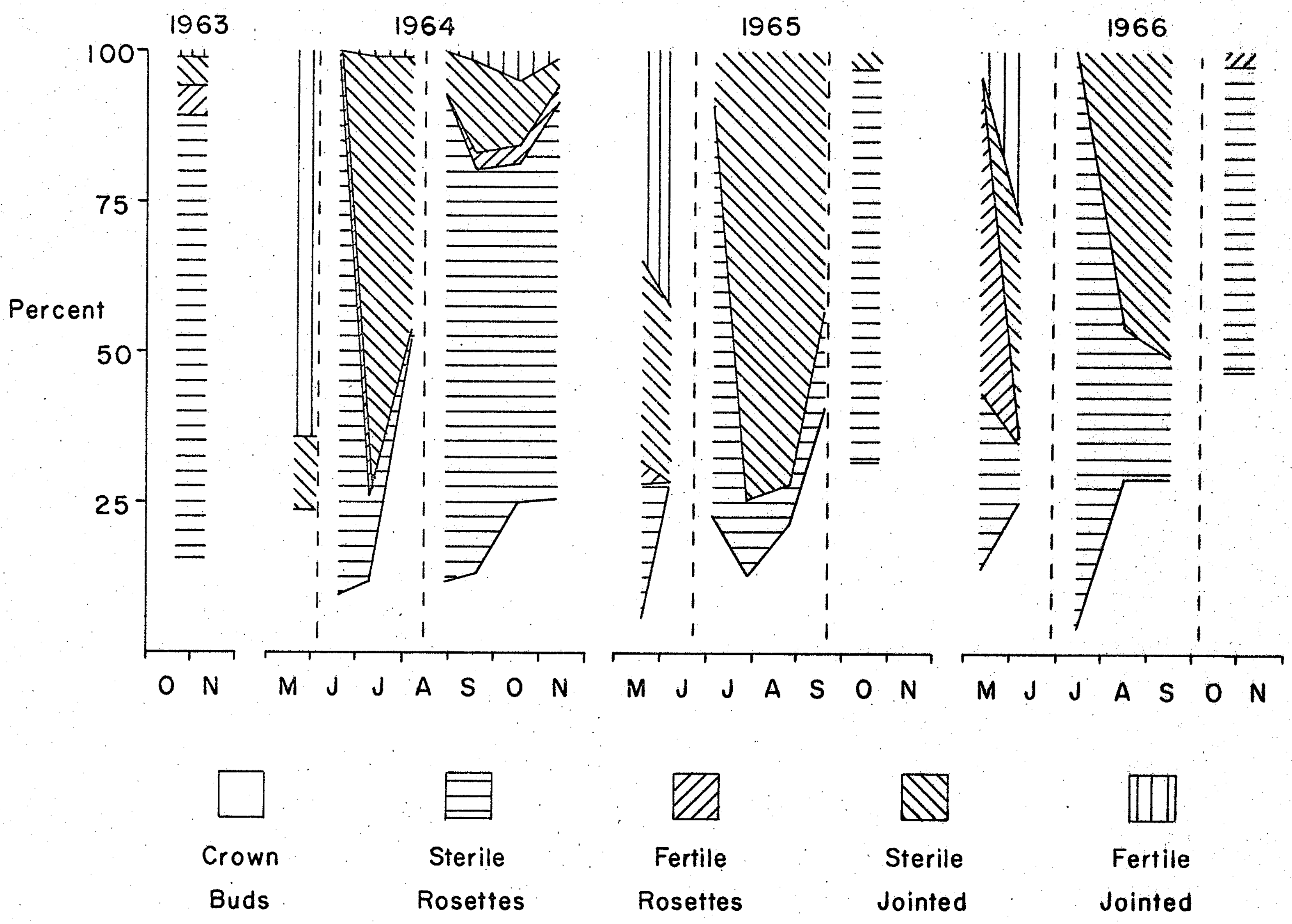
Relative proportions of the five tiller types in bromegrass grown on an area fertilized in spring and cut for forage twice per year



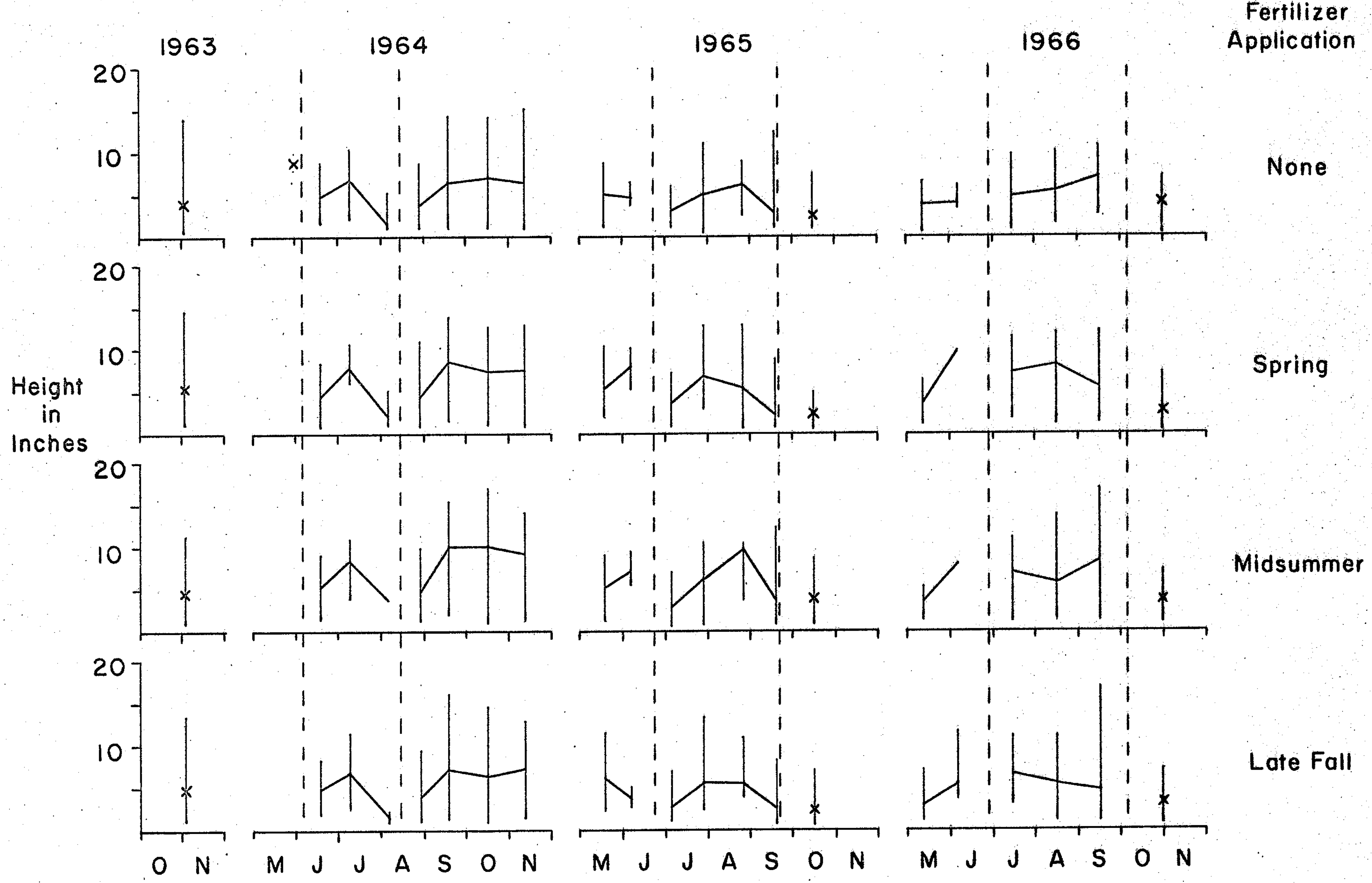
Relative proportions of the five tiller types in bromegrass grown on an area fertilized in midsummer and cut for forage twice per year



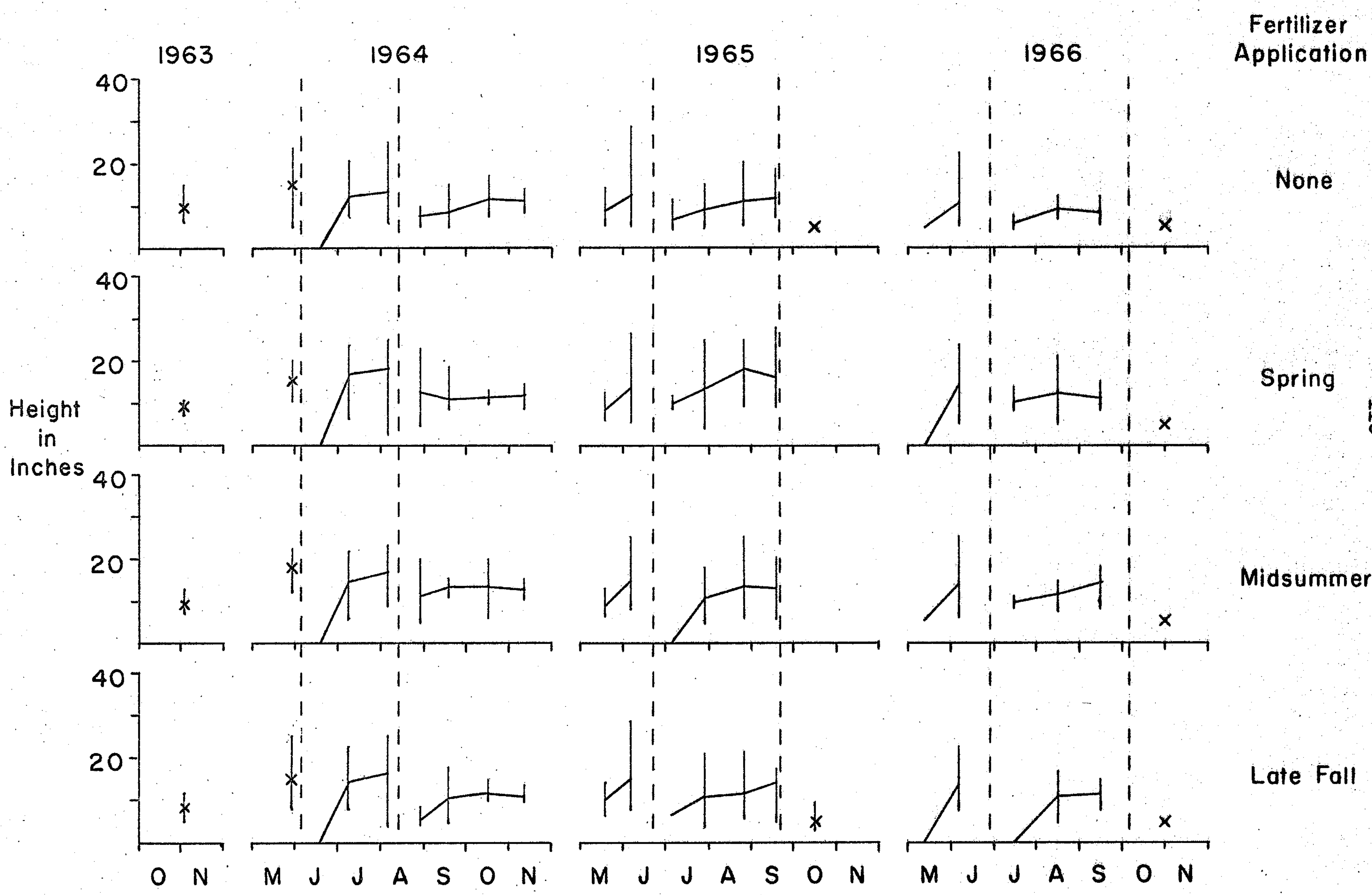
Relative proportions of the five tiller types in bromegrass grown on an area fertilized in late fall and cut for forage twice per year



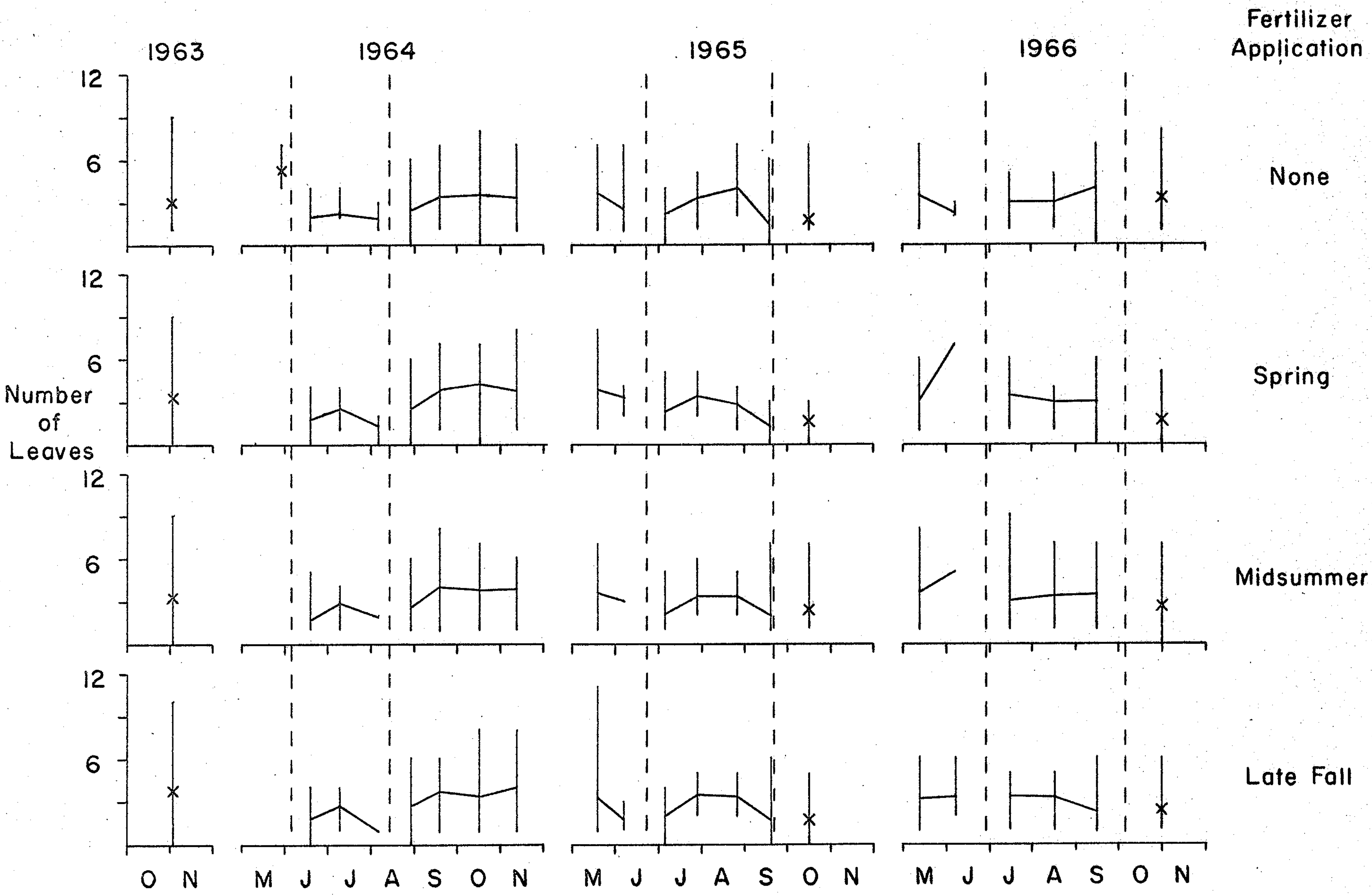
Height of sterile rosette tillers in bromegrass cut for forage twice per year



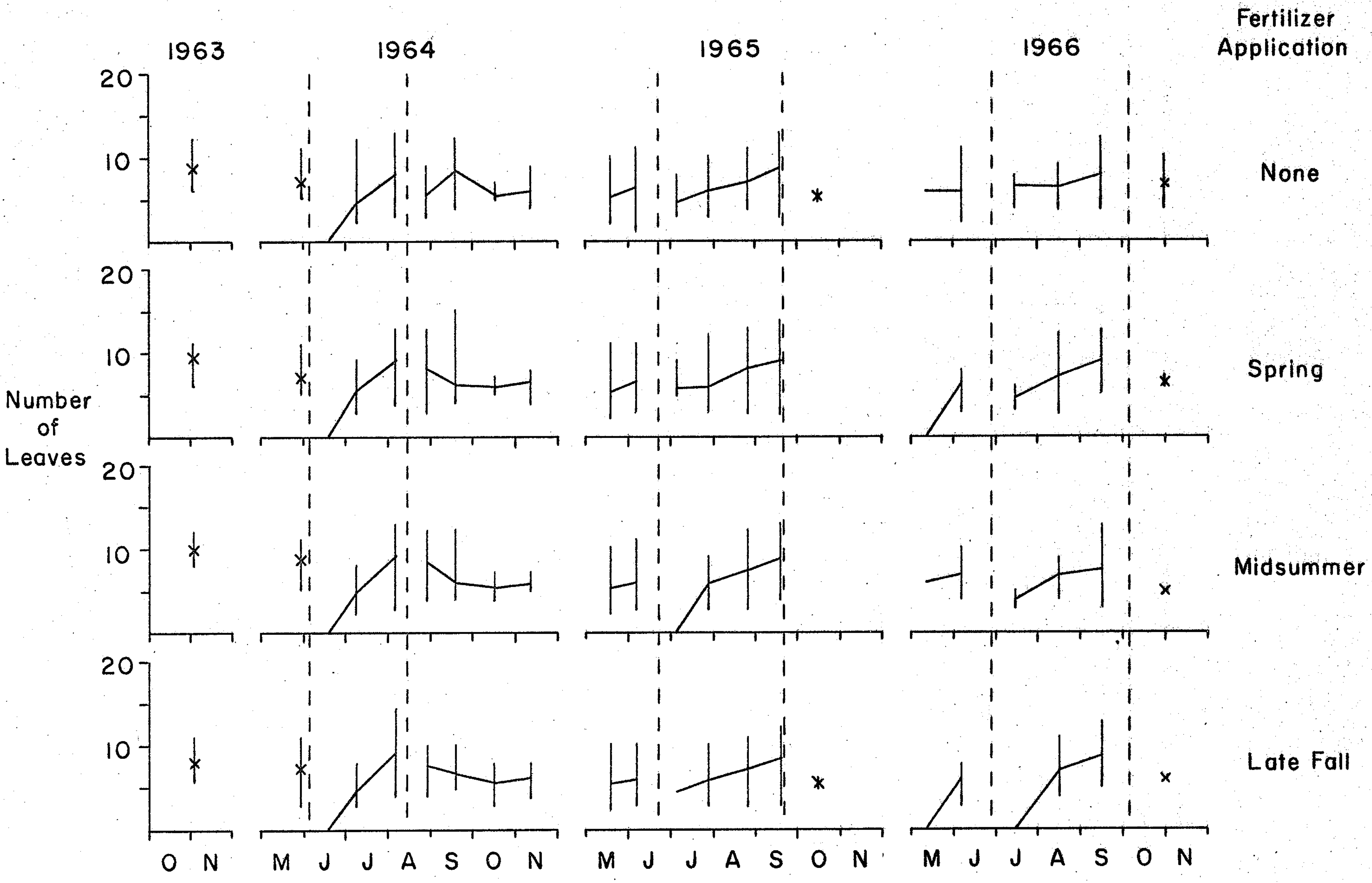
Height of sterile jointed tillers in bromegrass cut for forage twice per year



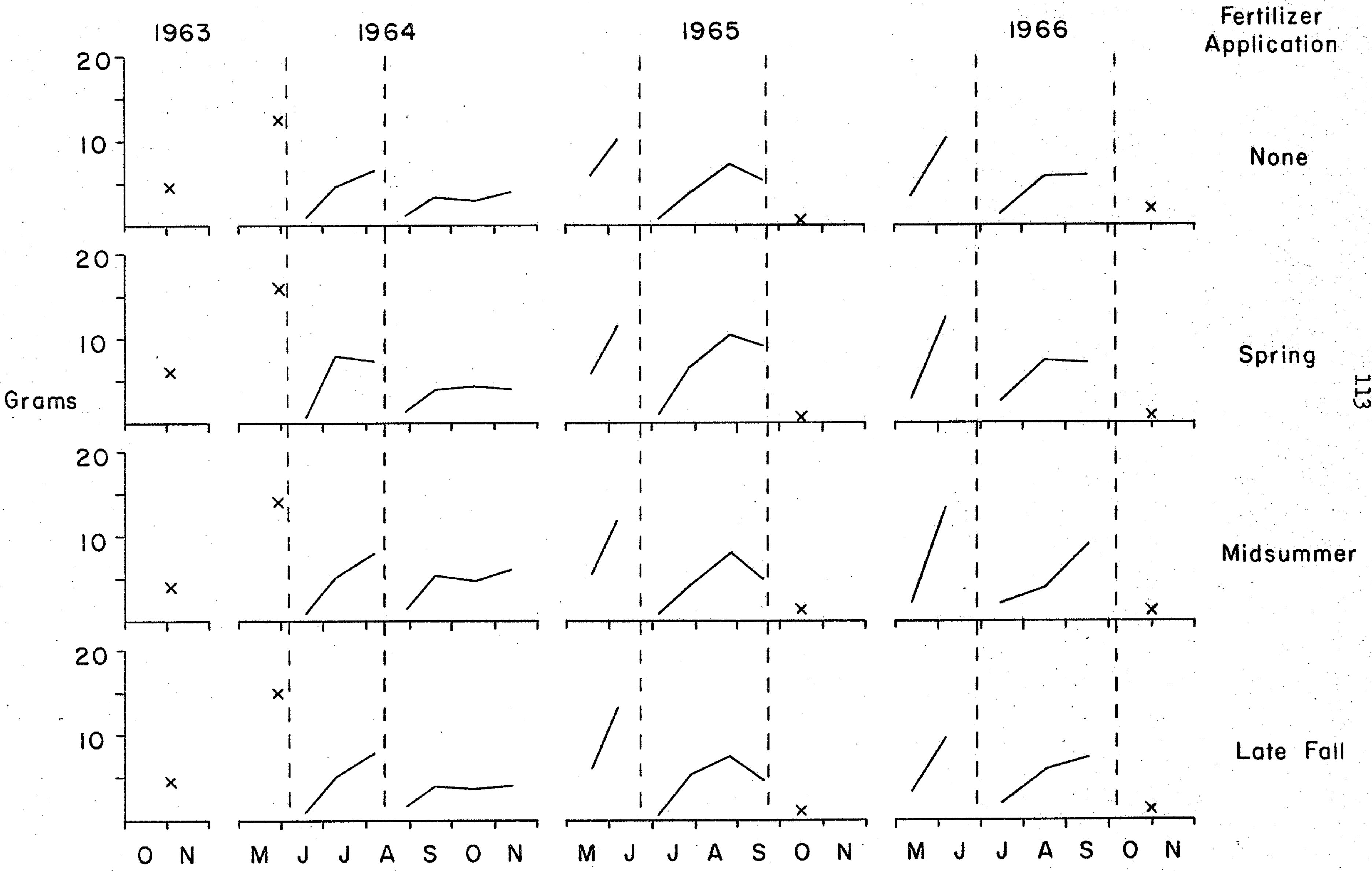
Number of leaves on sterile rosette tillers in bromegrass cut for forage twice per year



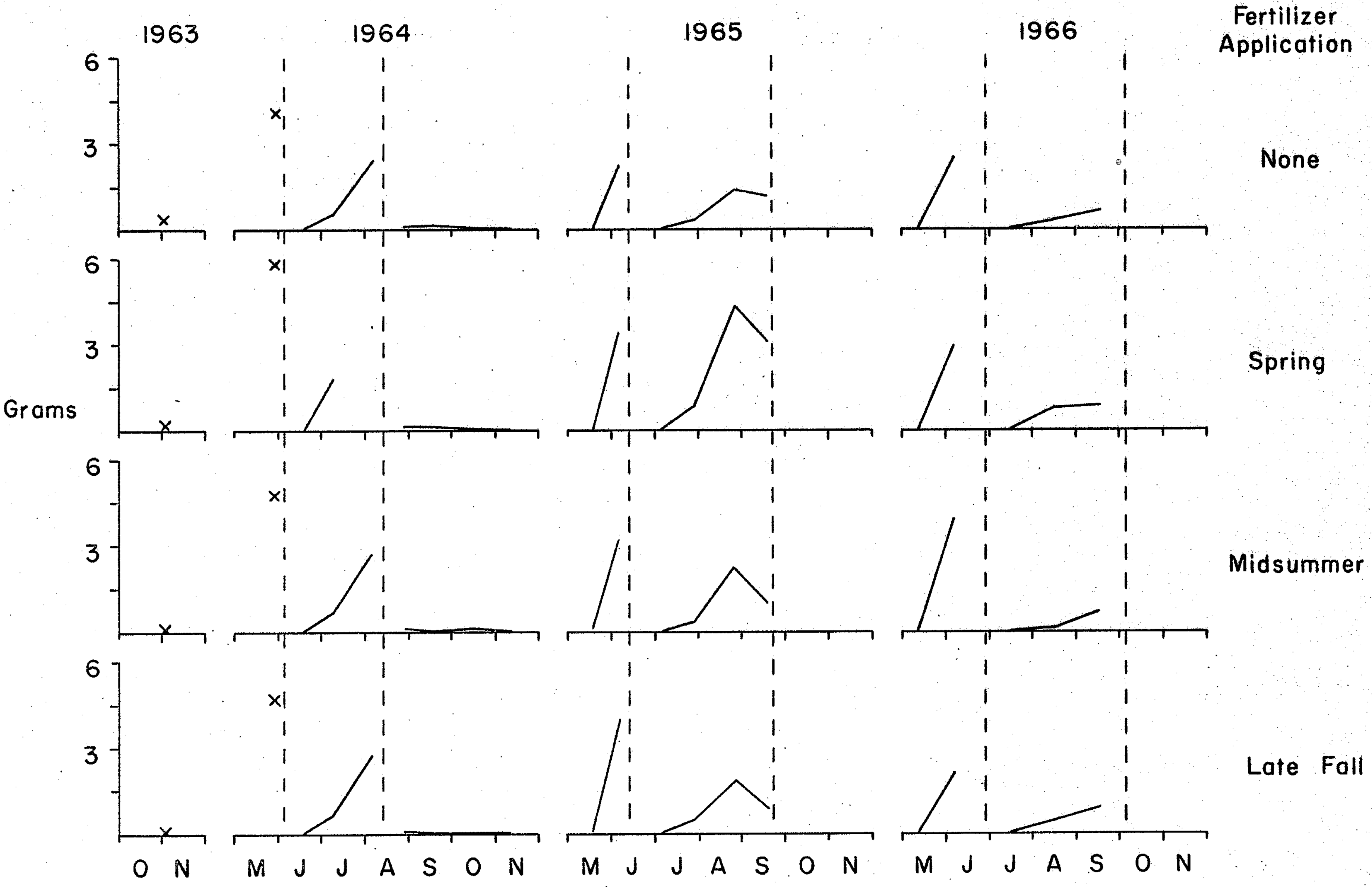
Number of leaves on sterile jointed tillers in bromegrass cut for forage twice per year



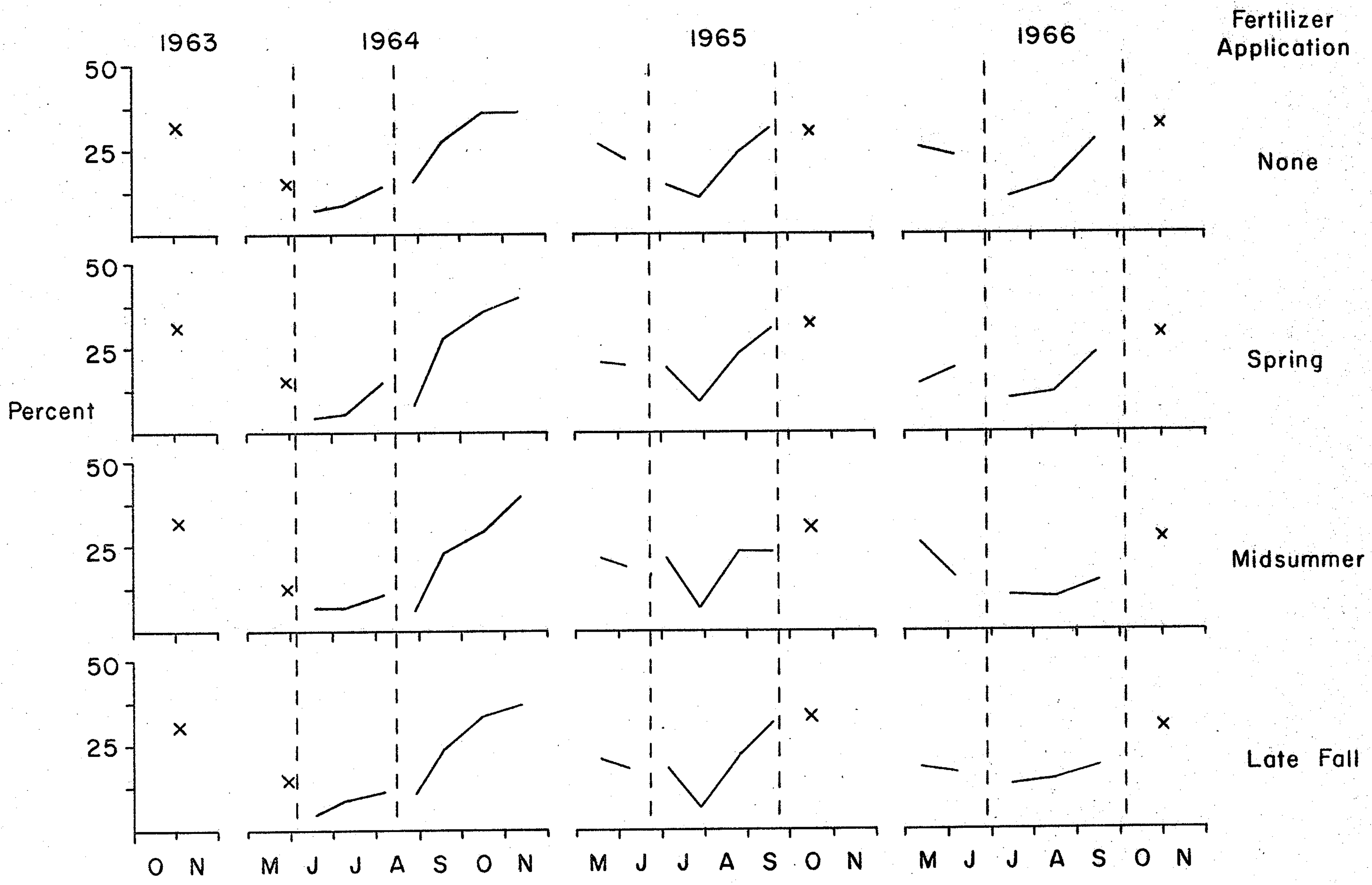
Dry weight of leaves of a fifty tiller sample from bromegrass
cut for forage twice per year



Dry weight of stems of a fifty tiller sample from bromegrass cut for forage twice per year



Acid soluble carbohydrate percentage content of rhizomes of bromegrass cut for forage twice per year



requirements during periods of regrowth (45, 46, 60, 63, 72). However, it is considered that only in June of 1964 did carbohydrate levels sink to values at which reserves might become the limiting factor controlling regrowth. At all other times, adequate reserves were present.

A visual examination of the experimental area each spring in the interval between the melting of the snow cover and the start of bromegrass growth revealed that all the jointed tillers and most of the leaf material had been killed during the preceding winter. In other words, the photosynthetic area was close to zero. This situation was very similar to that of the sward immediately after a harvest (Figures 23, 33) when almost all the photosynthetic material had been removed with the jointed tillers.

In each case, the regrowth pattern was basically the same: a development of crown buds to rosette tillers by production of green leaves, and development of rosette tillers to jointed tillers by the elongation of internodes. However, the time of year at which growth reached the rosette stage had a profound effect on further development. Three periods were observed: -

<u>Period 1</u> - The spring period. Growth at that time of year was less from crown buds than from rosettes which had survived the winter. The principal differentiating factor of the spring period was tiller

fertility. At some stage during the winter, some bromegrass growing points reached a "ripe to flower" stage (17, 54). Visually, this was detected only when the development of the tiller apex had reached the "double ridge" state.

Of the many tiller growing points examined, only two from crown buds were classified as developing inflorescences. All other growing points which had reached at least the "double ridge" stage were from rosette tillers or jointed tillers. It is clear that the claim by Lamp (36) that detectable inflorescences appear first at the rosette tiller stage was sustained by the present investigation.

It was less clear whether any change in growing point apparent status from sterile to fertile took place after internode elongation commenced. However, in the data collected in 1966 (Figures 14, 15, 16, 17, 25, 26, 27, 28) the proportions of fertile jointed tillers at the end of May after internode elongation had been progressing for three weeks were never greater than the proportions of fertile rosette tillers at the start of jointing. This fact suggests that Lamp's conclusion (36) of no fertile tiller production after the start of jointing is correct.

Fertile jointed tillers grew approximately twice as fast as sterile jointed tillers (Figures 8, 9). Along their four feet of stem length at maturity were 6 to 7 leaves. Along the two foot length of the sterile tillers were 11 to 12 leaves (Figure 11). No measurements were made on the relative production of stem and leaf of the two jointed tiller types individually. However, the leaves produced by the fertile tillers were observed to be much larger than the leaves produced by the sterile tillers and this would in part compensate for their fewer numbers. It is likely that part of the spring flush of growth and the consequent preponderence of forage material produced at that time (10, 47, 59) is due to the presence of the fast growing, large fertile tillers.

Period 2 - The summer period. Growth after a harvest during the period June through August was principally from crown buds because the rapid jointing in late spring reduced the rosette tiller numbers to near zero. The distinguishing feature of summer regrowth was the infrequency of fertile tillers. The small proportion of fertile tillers which appeared can be ascribed to late starters, from the spring jointing period having evaded clipping by having their growing points too near the ground (59) or to a small number of tillers or plants which have little or no cold requirement for flowering (cf. 25). They constituted less than five per cent of the tiller population at all times after the first harvest, had no effect on the main tiller development during most of the year and so after the spring period of growth they were ignored.

A principal feature of both spring and summer growth was the transitory nature of the rosette tillers. As soon as the rosettes had accumulated three leaves on average, jointing commenced at the internode between the first and second leaf. This resulted in sterile jointed tillers which had on average, one more leaf than the number of extended internodes per tiller (Figures 11, 21, 32; Appendices 9, 16, 26).

During the spring and summer periods, bromegrass growth showed a distinct cyclic nature. Growth started in mid-April and prior to mid-May, internode elongation commenced. During 1964, 1965 and 1966, top growth was harvested at several dates in June, July and early August (Table 2), each time removing most of the photosynthetic tissue. In each case, regrowth from crown buds commenced immediately and had progressed through the rosette stage and had produced jointed tillers within a 30 day period from the date of cutting (Figures 3, 4, 5, 6; 14, 15, 16, 17; 25, 26, 27, 28).

The shortest period between the start of growth from crown buds and the harvest date was seven weeks and extended from the start of growth in mid-April to the harvest on the fifth of June in 1964. By this time, crown buds represented 35% to 40% of the tiller population, and subsequent regrowth demonstrated that crown bud density was satisfactory for replacement of the tillers removed (Figures 25, 26, 27, 28).

Teel (64) gave four growth stage characteristics of a bromegrass sward which indicated when semi-dormancy would follow cutting. These were:- rapid growth, internode elongation, low carbohydrate reserves, and an absence of new tiller growth. He further qualified the stage to which he attached the term "juvenile" as ending when panicles emerged from the flag leaves of the fertile tillers. In the present experiment, the cut on June 5th in 1964 was made at the stage when panicles were emerging from the flag leaves. As this cut was taken after the shortest growing interval during the entire experiment, it is clear that there was little danger of inducing dormancy during the current series of studies.

A closer examination of some of the data revealed that for a period after a harvest, the proportion of crown buds in a population was only 10% to 20% (Figures 25, 26, 27, 28). Apparently, the reason for no new tiller growth during Teel's "juvenile stage" (64) was that insufficient crown buds were present. It should be noted that large numbers of small nodal buds at a very early stage of development were observed in all tiller samples. These buds were much smaller than crown buds, had only 1 to 3 leaf initials surrounding a very small growing point and were too immature to produce aerial tillers immediately in response to a growth stimulus.

An interval of from four to six weeks elapsed between harvest and the commencement of an increase in crown buds in the sward. Removal of the top growth in this interval would delay or reduce regrowth because of insufficient tiller apexes to produce the regrowth. Clearly, both this work and that of Teel (64) agree that a critical stage exists during the growth of bromegrass, that this stage encompasses an interval during which rapid growth and jointing are occurring, and that very poor regrowth will occur if a harvest cut is taken while the grass is at this stage of growth.

Period 3 - The fall period. This interval extends from mid-August to the end of the growing season in late October. It consists characteristically of falling temperatures and shortening daylengths. During this period, crown bud initiation and growth were found to take place continuously. The first two weeks overlapped with the summer period and in 1965, some development of jointed tillers occurred (Figure 25). After August, tiller development stopped at the rosette tiller stage. At no time in the fall period was cutting data critical for tiller development. As many growing points were at or below ground level, only very close grazing would remove all the photosynthetic tissue. Under the conditions applied, three inches of stubble remained after harvest. Consequently, a cut during the fall period removed leaves only, and growing points together with a considerable amount of photosynthesising tissue remained. Growth did not have to start from crown buds so the cyclic nature of growth characteristic of spring and summer was not present in the fall.

The harvesting of bromegrass in September reduced the photosynthetic tissue considerably. When alfalfa is cut in September, the storage of food reserves for winter survival is interrupted (59). In bromegrass, this was apparently not the case. The increase in soluble carbohydrate levels in the rhizomes continued without interruption through the harvest period (Figure 35). Fertilizer added to the plots in midsummer produced a distinct slowing down of soluble carbohydrate accumulation in the fall following the fertilizer application, but this reduction was temporary and the percentage of soluble carbohydrate in the rhizomes by the end of the growing season was similar under all treatments (Figures 13, 24, 35).

The rapid increase in soluble carbohydrates in the rhizomes during late summer and fall was caused partly by photosynthesis and partly by the breakdown of insoluble carbohydrates. Experimental hydrolysis of the insoluble carbohydrates left after extracting the soluble ones produced variable results due to inadequacies of the technique, but there was a consistent decrease of insoluble carbohydrates in the rhizomes during the fall period for each sample in each year. It is suggested that the known (59) relative insensitivity of bromegrass and of grasses in general to fall management practices in relation to winter survival is due to a large proportion of the soluble carbohydrate apparently needed for winter being produced from the breakdown of insoluble carbohydrates already in the rhizome tissue and so being unaffected by management practices.

No definite effect on fertile-sterile tiller ratio could be ascribed only to harvesting in the fall. However, the fertile/sterile tiller ratio in the non-fertilized plots in the spring of 1966 was lower under the two cuts per year regime than under the one cut per year treatment (Figures 3, 25). Possibly the combined effects of low fertility and two cuts per year reduced the proportion of tillers. Watkins (70) observed that the addition of nitrogen to brome plots increased the fertile/sterile tiller ratio whilst shading decreased it. If cutting off tillers had a similar effect on the sward as shading, the grazing or mowing in the fall of bromegrass regrowth could have led to reduced seed yields the following year. The apparent opposite effect noted in Russian Wild Ryegrass (Elymus junceus), namely that fall grazing is necessary for good seed yields (42), is due to such treatment forcing the growing points to remain below soil level and so being protected during the winter. Bromegrass growing points are always produced below soil level. In the present experiment, seed was not harvested from plots given an additional mowing treatment in fall, so a comparison of seed yields under one and two cuts per year could not be made.

From a forage production viewpoint, fertile tillers are not important per se; vegetative production is the important factor. The effects of added fertilizer on tiller vegetative growth and development can be considered from two viewpoints; the long term effects and the immediate effects.

The long term effects of fertilizer application to bromegrass areas have been described and discussed extensively in the literature (6, 9, 13, 14, 55, 71). In short, bromegrass stands, in the absence of additional sources of fertilizer, particularly of nitrogen, have a much lower tiller density per unit area than areas adequately fertilized, and forage yields are also much reduced. By 1966 the non-fertilized plots in the present experiment showed similar symptoms which were clearly reflected in production (Tables 6, 7, 8, 9).

On an individual tiller basis, differences in growth between fertilized and non-fertilized areas were mainly reflected in height. Sterile jointed tillers from non-fertilized areas were shorter in the regrowth in 1964, and were shorter at all times in the 1965 and 1966 growing seasons (Figures 8, 19, 30). A similar difference in the fertile jointed tillers did not appear until 1966 (Figure 9). Also, shorter sterile rosette tillers were most clearly present in non-fertilized areas only in 1966 (Figures 7, 18, 29). Watkins (70) also observed increases in tiller height when bromegrass was fertilized.

It was observed that tiller growth rate was frequently slower in non-fertilized plots. This appeared in the results as a difference in the relative proportions of the five tiller groups in the non-fertilized areas compared to the fertilized areas. The difference was particularly evident in the plots cut only once per year. In the 1966 regrowth, few jointed tillers were produced in the non-fertilized areas: growth was slow and daylength was insufficient for internode elongation by the time growth of the rosette tillers was sufficiently advanced. In contrast, areas receiving fertilizer produced a proportion of jointed tillers in the regrowth similar to the proportion in the spring growth (Figures 2, 4, 29, 31).

Crown buds were replaced more slowly in non-fertilized areas, particularly in 1966 (Figures 3, 14, 25). The slower growth of crown buds in a low nitrogen regime resembled the behaviour of couchgrass (Agropyron repens)in similar conditions. McIntyre (48) found that couchgrass crown buds usually remained dormant when the soil nitrogen level was low, but that at high nitrogen levels, tiller emergence was markedly increased.

The more immediate effect of fertilizer application was to increase growth rate for one to four weeks after the addition of fertilizer. The effect appeared most clearly in the tiller regrowth after a harvest, and particularly in plots fertilized in spring. Jointing of the rosette tillers proceeded more rapidly (Figures 14, 15, 25, 26). The same effect was produced later in the year by the application of fertilizer in midsummer (Figure 5).

The faster growth rate was also visible as an increase in tiller height, leaf and stem protein content and as a decrease in rhizome carbohydrate content. There was no clear evidence for an increase in the rate of leaf production as Watkins (70) and McIntyre (48) observed when they applied nitrogen, but as they found the increase to be small and of short duration it is probable that the effect would not be detected in the present results.

Not every application of fertilizer produced a detectable increase in the observed features, and it was frequently difficult to differentiate between the temporary effects due to the sudden improvement of nutrient status and the accumulative differences between growth on fertilized and on non-fertilized areas.

The effects of fertilizer were confounded to some extent with water supply. Growth during the experimental period was entirely dependent on the amount of winter snowfall retained as soil moisture in spring and on the rainfall during the growing season.

Few jointed tillers were produced in the dry period following the seed harvest in 1965 (Figures 3, 4, 5, 6). Regrowth took place only to the rosette tiller stage and response to fertilizer was not obtained. It is possible that drought delayed growth sufficiently to prevent tillers reaching the jointing stage until after daylength was too short for internode elongation. Jointing was not prevented by a similar dry period after the hay harvest on the 7th of July, 1964, but was accelerated in the plots fertilized that spring.

Other harvests were followed within a short time by rainy periods, but not by consistent fertilizer responses. Clearly, the present study has not completely clarified the complex relationship of fertilizer status, available water and bromegrass growth.

CONCLUSIONS

Bromegrass commences growth in mid-April at the latitude of Winnipeg from rosette tillers and crown buds which have survived the winter. Few tillers remain dormant.

Jointing commences in the second week in May and its start is controlled by temperature. The majority of tillers which start growth in the spring produce jointed stems.

If bromegrass is left undisturbed, a second phase of crown bud growth commences not earlier than the end of July. There is no single factor controlling the resumption of crown bud activity. Probably, factors affecting the development of crown buds prior to their production of leaves determines when the second growth phase commences.

The second growth phase continues until the end of the growing season in late October. During this period, growth from crown buds to jointed tillers takes place continuously. Tillers are initiated, develop to maximum crown bud size and produce green leaves. Further growth to the jointed tiller stage takes place only in August. Throughout this second growth phase, all sizes of all tiller stages can be found.

During the period from the end of May to mid-August, cutting bromegrass results in a recycle of the early spring growth pattern. Cutting after mid-August does not deflect regrowth from the pattern of the second growth phase.

Jointing stops in late August. Its cessation coincides with the reduction of daylength to less than 15 hours.

The only times in the year when there are too few crown buds for adequate regrowth is 3 to 4 weeks after growth starts in spring and 3 to 4 weeks after a harvest cut has been taken in the period ending in mid-August. At all other times, sufficient crown buds are present to replace the tillers removed.

A single cut per year or a two cuts per year management system did not deplete carbohydrate reserves to a level at which growth was adversely affected.

The addition of nitrogenous phosphatic fertilizer (27-14-0) at 185 pounds per acre prevents or reduces the steady diminution of forage and seed yields with increasing age of stand which characterizes non-fertilized bromegrass areas. The diminution in yield is caused by reduced tiller density per unit area, by reduced size of jointed tillers and to a lesser extent of rosette tillers, and by a reduction in protein content of plant parts. Fertilizer, irrespective of the time of application, prevents or reduces the diminution in tiller size, density, and protein content.

Fertilizer use also causes a more rapid regrowth immediately after a harvest, particularly if applied 2 to 4 weeks before the harvest date. The faster regrowth is reflected in an increased loss of soluble carbohydrate reserves during the same period.

Apart from the temporary effect noted above, fertilizer has no effect on the rate of leaf exsertion nor on the final number of leaves produced.

The effect of fertilizer on the fertile/sterile tiller ratio was not clear. There was an indication that fewer fertile tillers were produced from non-fertilized areas which were cut in late September. Further research will be necessary to clarify this relationship.

An application of fertilizer in spring produced the most equitable distribution of forage yield between first and second cuts. The reason is probably that faster regrowth after the first cut enables the sward to take fuller advantage of the good daylength conditions during July and June.

An application of fertilizer in late fall was most effective in producing the highest yield at the first forage cut in spring. It is suggested that the fertilizer application late in the fall enables the sward to take maximum advantage of favourable spring moisture conditions. An application split between late fall and spring might obtain the advantages of both times.

An application of fertilizer in midsummer increases forage and protein yields from harvests made in late September.

The relative insensitivity of bromegrass to winterkill caused by mowing or grazing in September is due to the fact that a large proportion of the soluble carbohydrate reserves necessary for winter survival are produced by the breakdown of insoluble carbohydrates already in the plant. This factor renders the plant relatively independent of photosynthetic area in early fall.

The relationship between rainfall and production of forage or seed was not clarified. The evidence indicates that the moisture factor interacts with fertilizer effects and possibly with daylength. A dry period following a harvest cut may cause poor regrowth.

The information gathered from this study suggests that bromegrass grown alone can be harvested for forage three times per year; in early June, in early August, and in early October. Fertilization in spring (early May) will increase the rate of growth after the first cut, and fertilization just before the second cut will increase production from the third cut. The third cut will never produce a high yield and would probably best be utilized as pasturage. Production from the second cut may also be poor if soil moisture is low during the early part of the second growth period.

A light grazing in the first week in May will probably do little harm although growth might be slower afterwards. Cutting or grazing in the period starting around mid-May and extending for three to four weeks might cause the semi-dormant reaction observed by Teel (64), because of insufficient crown buds to replace the tillers removed. A period of similar length should be left after any harvest taken before mid-August.

For maximum hay and seed yields, application of fertilizer the previous fall appears to be best because of the faster growth produced early in the year after application. Removing in September or October the regrowth after a hay or seed crop should not reduce the stand density. The effect on seed production could be deleterious.

For forage production, bromegrass might best be exploited during spring and summer for either hay production or rotational grazing with a six week recovery period between grazings. In the fall, continuous grazing would not greatly harm it.

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APPENDIX 1

Preparation of the Dinitrosalicylate Reagent Used For Carbohydrate Determination

Moisten 10 grams 3,5-dinitrosalicylic acid with distilled water.

Add 200 millilitres 2N sodium hydroxide a little at a time stirring continuously.

Add 500 millilitres distilled water to dilute.

When the sodium dinitrosalicylate has dissolved, add 300 grams sodium potassium tartrate and stir.

Allow the reagent to cool, make up to one litre with distilled water, then filter.

APPENDIX 2

Preparation of a Standard Graph of the Relationship Between the Concentration of Maltose in a Solution and its Optical Density After Development with Dinitrosalicylate Reagent

A solution of 1.2 grams maltose per litre was made as a standard. This was diluted according to the following scheme:-

Standard Solution (ml.)	Distilled Water (ml.)	Maltose in 2 ml. of resultant solution (mg.)
12	0	2.4
10	2	2.0
8	4	1.6
6	6	1.2
4	8	0.8
2	10	0.4
2	22	0.2

To estimate the colour density, 2 millilitres of maltose solution was mixed with 2 millilitres dinitrosalicylate reagent and heated in boiling water for exactly five minutes, cooled in ice water and diluted with 20 millilitres distilled water. The optical density was read on a colorimeter at a wavelength of 505 microns against a blank.

The optical density of each of the seven dilutions was plotted against its maltose content. The graph obtained was used to estimate unknown sugar concnetrations by interpolation.

Appendix 3

Analyses of variance of yearly seed yields from "Lincoln" bromegrass grown at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1964	Total	15	165,085.75			
	Replications	3	27,999.25	9,333.08	0.70	N.S.
	Fertilizer	3	17,444.25	5,814.75	0.44	N.S.
	Error	9	119,642.25	13,293.58		
1965	Total	15	65,472.06			
	Replications	3	14,821.31	4,940.44	1.08	N.S.
	Fertilizer	3	9,518.22	3,172.74	0.70	N.S.
	Error	9	41,132.53	4,570.28		
1966	Total	15	56,626.78			
	Replications	3	29,867.41	9,955.80	9.42	1%
	Fertilizer	3	17,250.73	5,750.24	5.44	1%
	Error	9	9,508.64	1,056.51		

Appendix 4

Analysis of variance of total seed yields of "Lincoln" bromegrass grown at Winnipeg with fertilizer applications at different seasons of the year

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	47	707,957.81			
Replications	3	21,895.89	7,298.63	0.73	N.S.
Fertilizer treatments	3	3,629.39	1,209.80	0.12	N.S.
Error I	9	89,861.20	9,984.58		
Years	2	420,748.87	210,374.44	36.74	1%
Replications x Years	6	50,886.80	8,481.13	1.90	N.S.
Fertilizer x Years	6	40,747.80	6,791.30	1.52	N.S.
Error II	18	80,187.86	4,454.88		

Appendix 5

Yearly analyses of variance of thousand kernel weights of seed produced by "Lincoln" bromegrass under various fertilizer treatments at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1964	Total	15	0.52020			
	Replications	3	0.11375	0.0379	1.02	N.S.
	Fertilizer	3	0.07075	0.0236	0.63	N.S.
	Error	9	0.33570	0.0373		
1965	Total	15	0.24472			
	Replications	3	0.04158	0.0139	0.78	N.S.
	Fertilizer	3	0.04225	0.0141	0.79	N.S.
	Error	9	0.16089	0.0179		
1966	Total	15	0.60760			
	Replications	3	0.04055	0.0135	0.55	N.S.
	Fertilizer	3	0.34725	0.1158	4.74	5%
	Error	9	0.21980	0.0244		

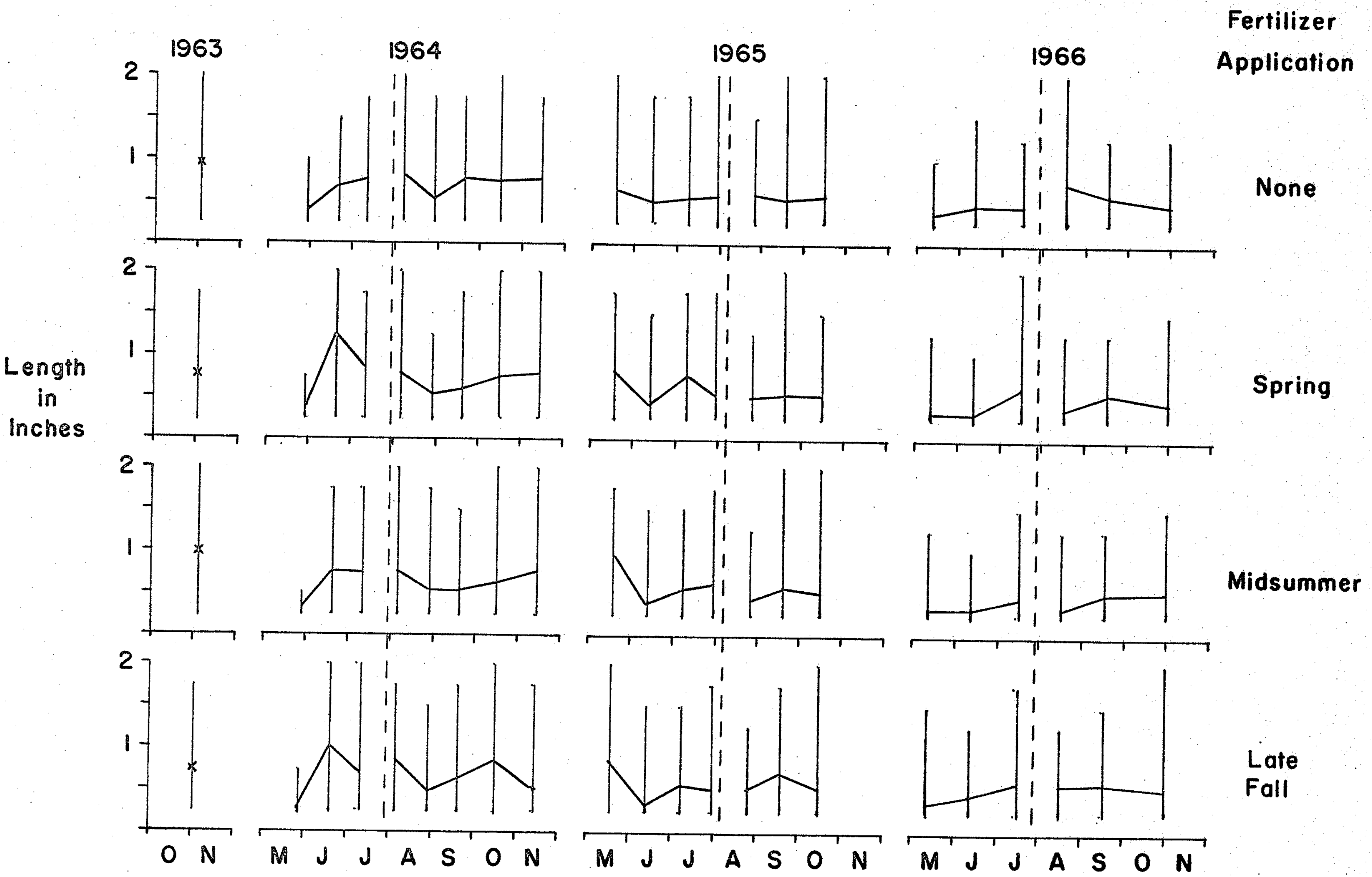
Appendix 6

Analysis of variance of thousand kernel weights of seeds of "Lincoln" bromegrass produced at Winnipeg

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	47	2.0086			
Replications	3	0.1345	0.0448	3.03	10%
Fertilizer treatments	3	0.1160	0.0387	2.61	N.S.
Error I	9	0.1332	0.0148		
Years	2	0.6336	0.3168	9.76	1%
Replications x Years	6	0.0623	0.0104	0.32	N.S.
Fertilizer x Years	6	0.3445	0.0574	1.77	N.S.
Error II	18	0.5845	0.0325		

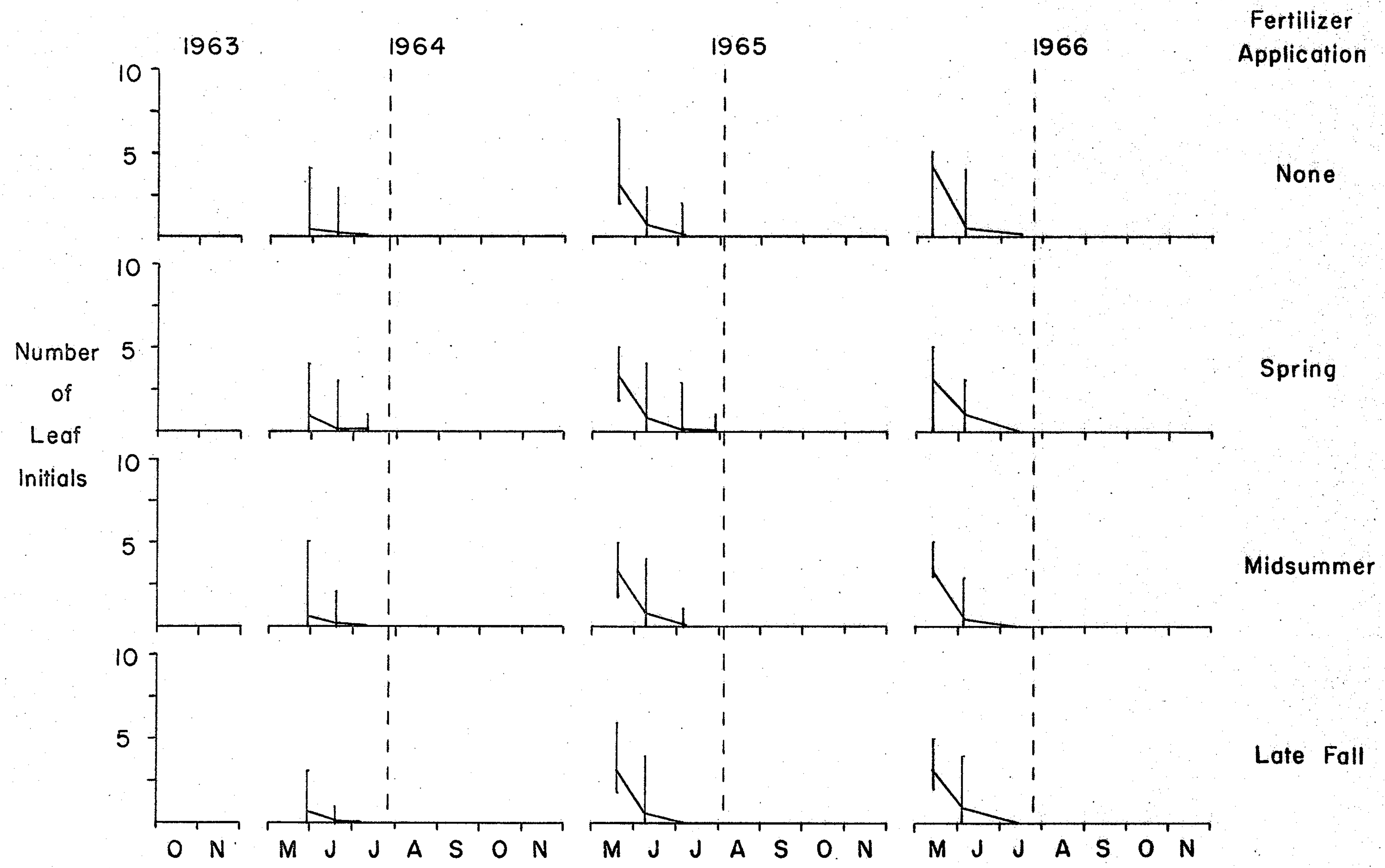
Appendix 7

Length of crown buds in bromegrass grown for seed



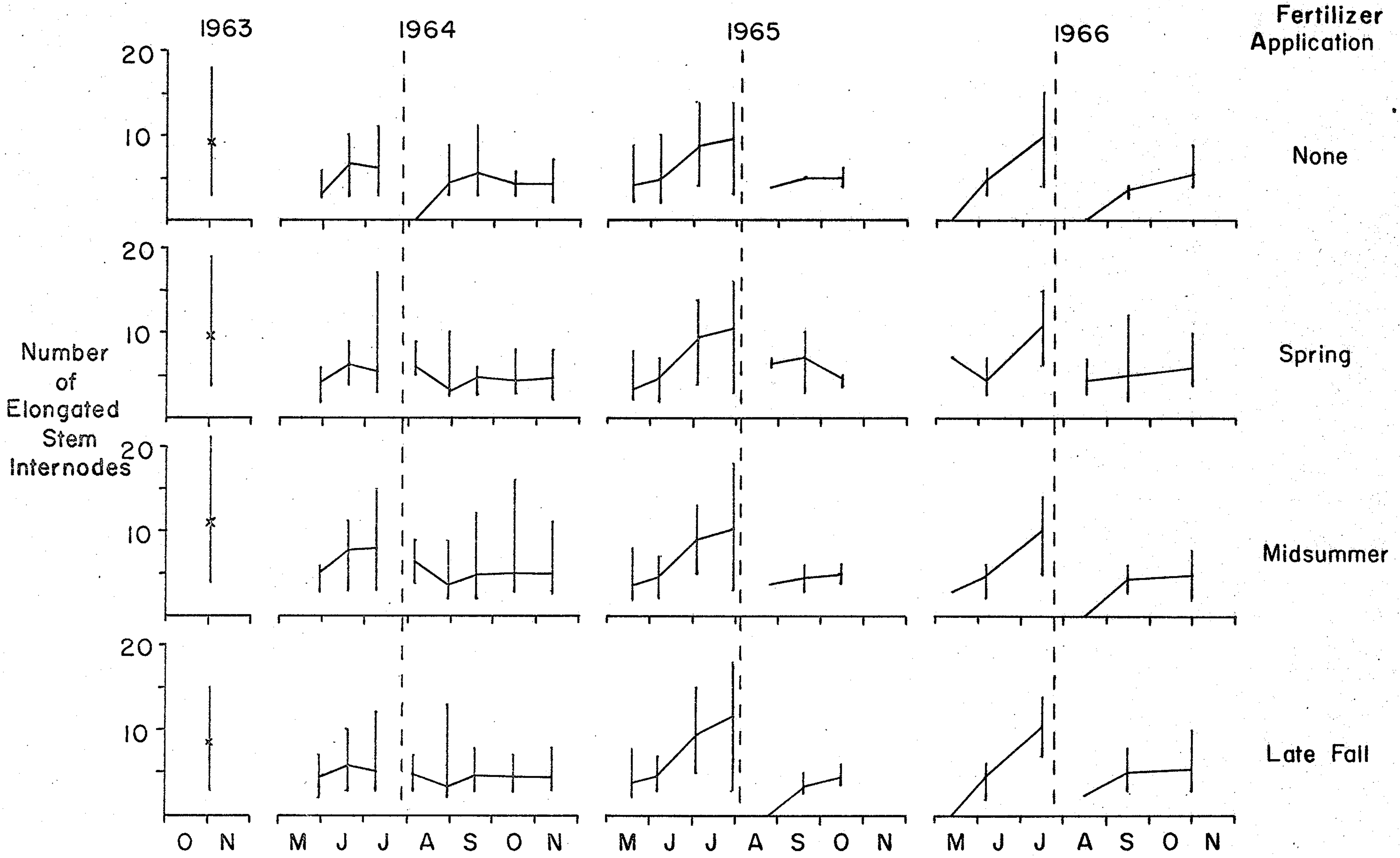
Appendix 8

Number of leaf initials on fertile jointed tillers of bromegrass



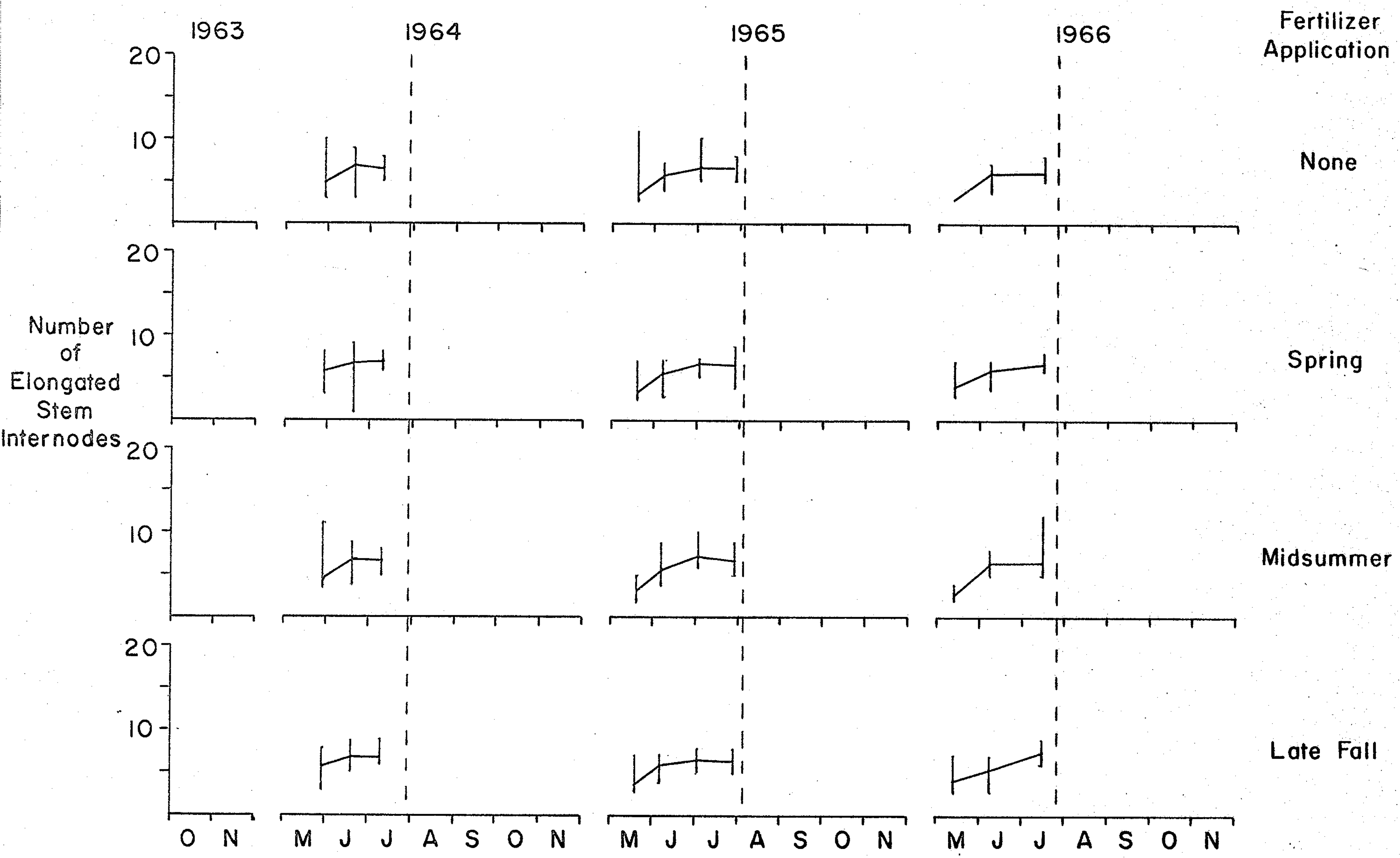
Appendix 9

Number of elongated internodes in sterile jointed tillers from bromegrass grown for seed



Appendix 10

Number of elongated internodes in fertile jointed tillers of bromegrass



Appendix 11

Analysis of variance of total dry matter production by the hay cut of "Lincoln" bromegrass grown under various fertilizer treatments at Winnipeg

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	47	136.05			
Replications	3	0.58	0.192	0.04	N.S.
Fertilizer treatments	3	45.02	15.006	3.17	10%
Error I	9	42.56	4.729		
Years	2	8.24	4.119	2.30	N.S.
Replications x Years	6	1.40	0.234	0.13	N.S.
Fertilizer x Years	6	6.05	1.008	0.56	N.S.
Error II	18	32.21	1.789		

Appendix 12

Analyses of variance of yearly dry matter production by the hay cut of "Lincoln" bromegrass grown under various fertilizer treatments at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1964	Total	15	35.3151			
	Replications	3	0.0964	0.0321	0.02	N.S.
	Fertilizer	3	20.5145	6.8382	4.19	5%
	Error	9	14.7042	1.6338		
1965	Total	15	47.5506			
	Replications	3	1.6788	0.5596	0.13	N.S.
	Fertilizer	3	6.7439	2.2480	0.52	N.S.
	Error	9	39.1279	4.3475		
1966	Total	15	44.9480			
	Replications	3	0.3044	0.1015	0.04	N.S.
	Fertilizer	3	23.8094	7.9365	3.42	6%
	Error	9	20.8702	2.3189		

Appendix 13

Analysis of variance of total crude protein production by the hay cut of "Lincoln" bromegrass grown under various fertilizer treatments at Winnipeg

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	31	1.8319			
Replications	3	0.1454	0.0485	0.64	N.S.
Fertilizer treatments	3	0.7418	0.2473	3.29	10%
Error I	9	0.6775	0.0753		
Years	1	0.1093	0.1093	18.78	1%
Replications x Years	3	0.1000	0.0333	5.73	5%
Fertilizer x Years	3	0.0055	0.0018	0.31	N.S.
Error II	9	0.0524	0.0058		

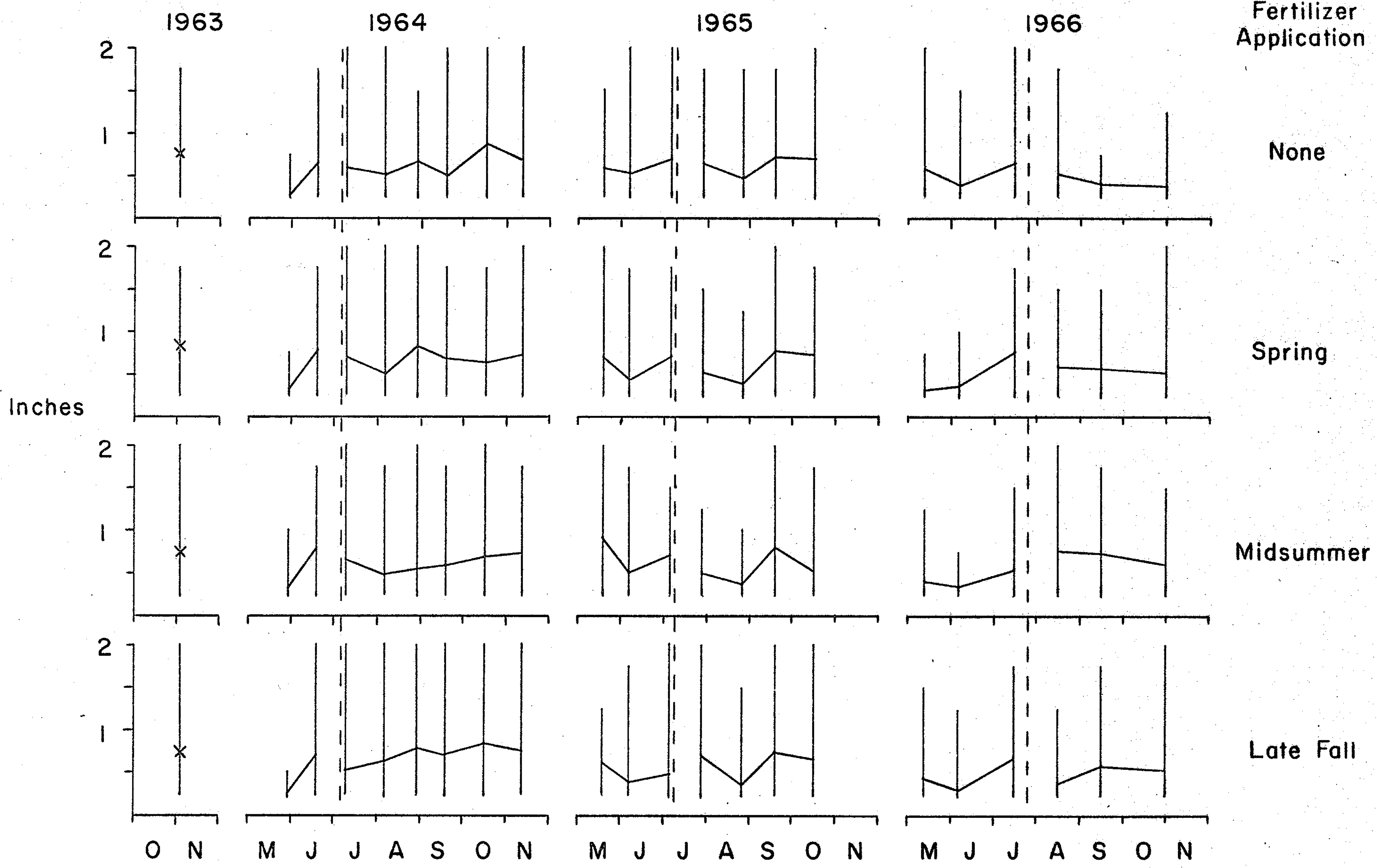
Appendix 14

Analyses of variance of yearly crude protein production by the hay cut of "Lincoln" bromegrass grown under various fertilizer treatments at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1965	Total	15	0.9462			
	Replications	3	0.1905	0.0635	1.45	N.S.
	Fertilizer	3	0.3616	0.1205	2.75	N.S.
	Error	9	0.3941	0.0438		
1966	Total	15	0.7764			
	Replications	3	0.0549	0.0183	0.49	N.S.
	Fertilizer	3	0.3858	0.1286	3.45	10%
	Error	9	0.3357	0.0373		

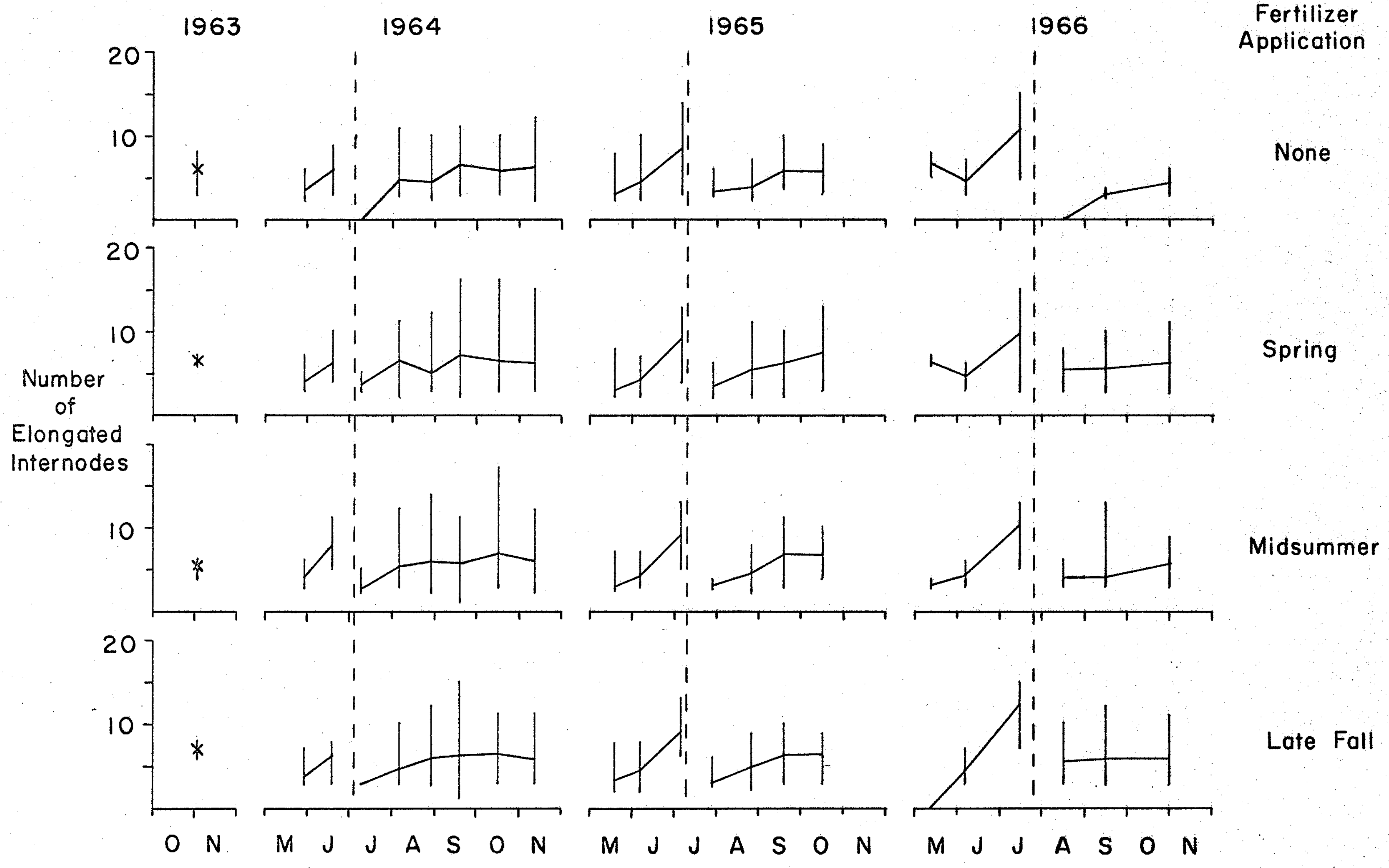
Appendix 15

Length of crown buds from bromegrass grown for hay



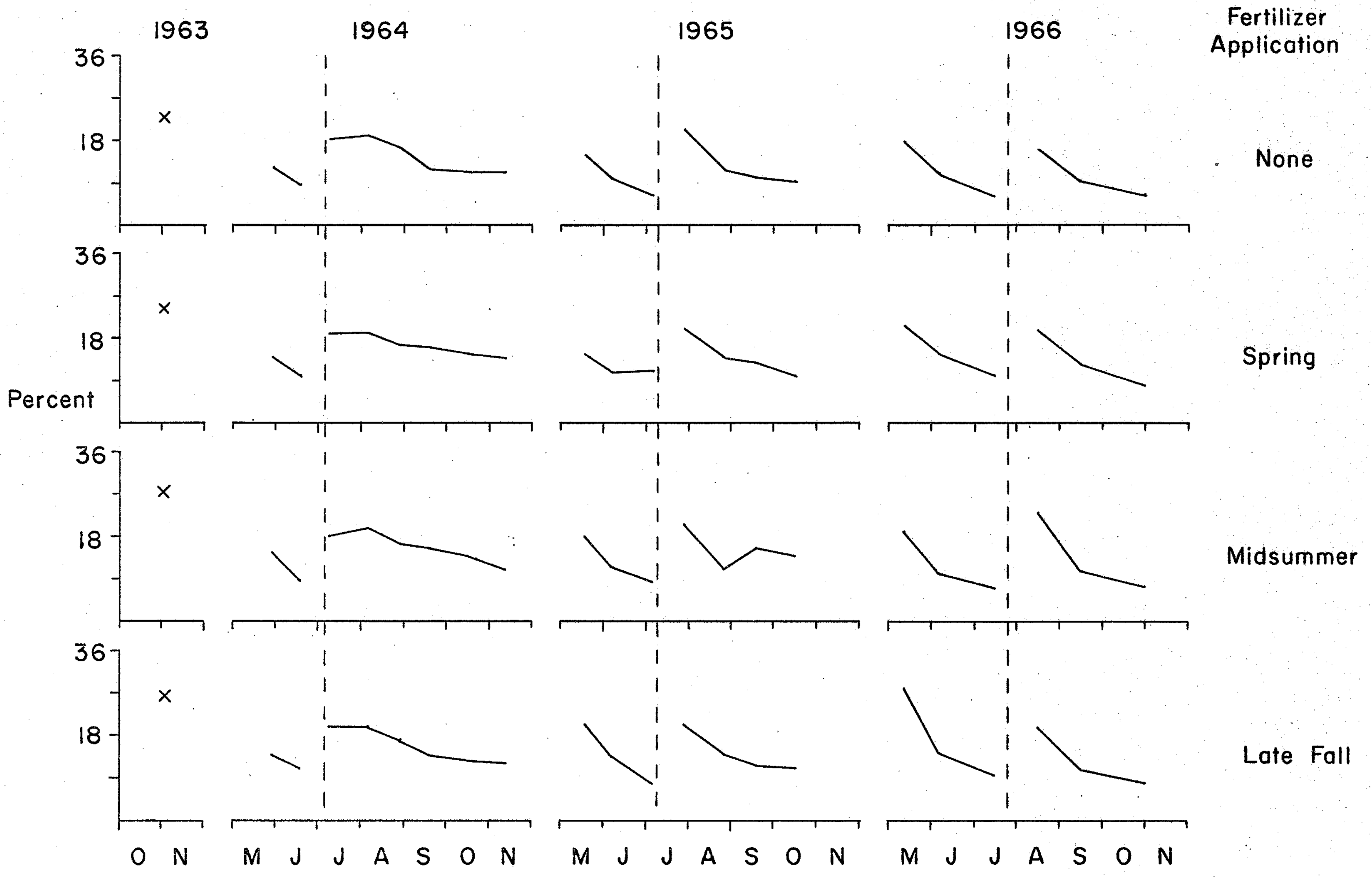
Appendix 16

Number of elongated internodes on sterile jointed tillers from bromegrass grown for hay



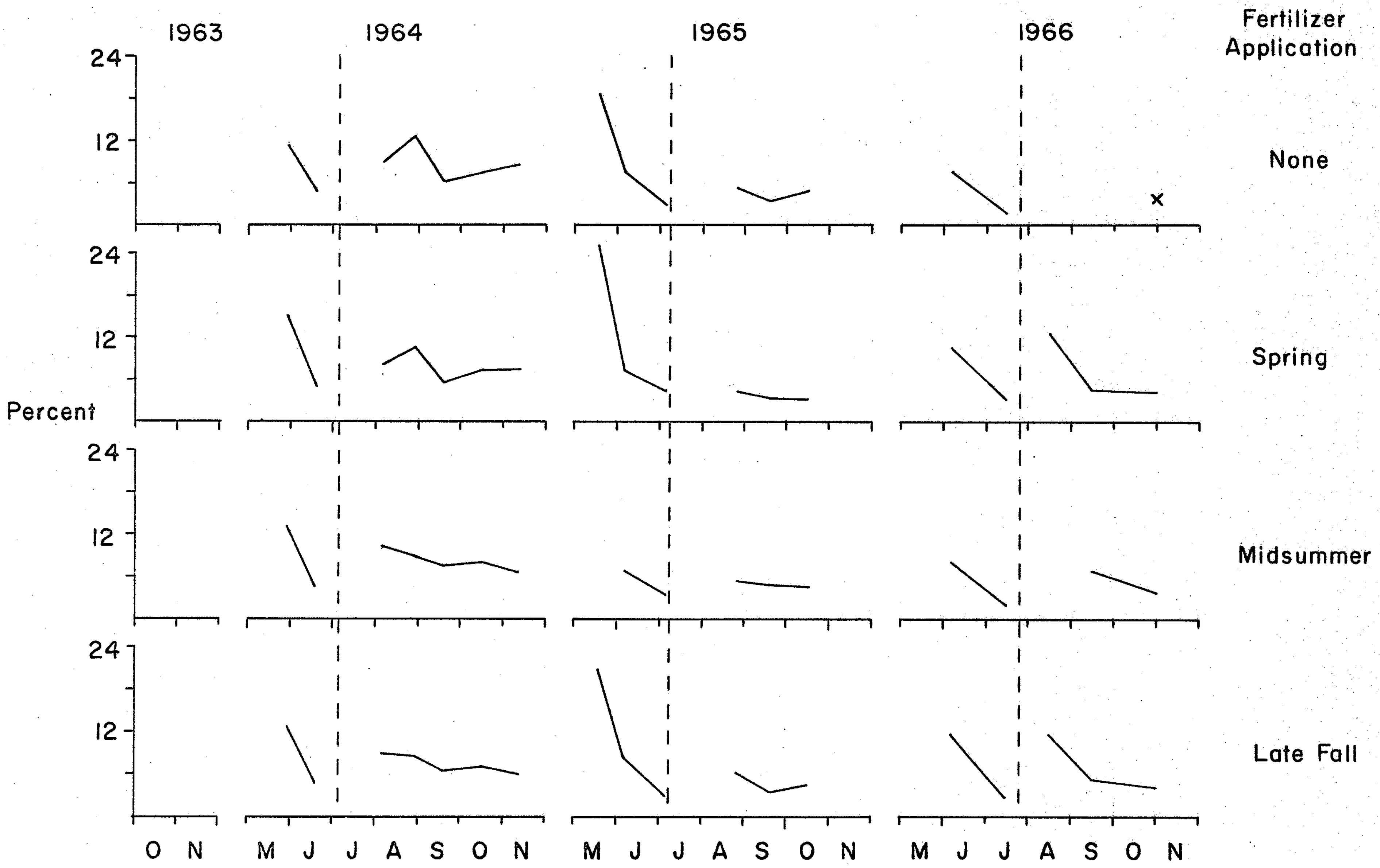
Appendix 17

Crude protein content of leaves from bromegrass grown for hay



Appendix [illegible]

Crude protein content of stems from bromegrass grown for hay



Appendix 19

Analyses of variance of dry matter production from the early summer cut of "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
	Total	15	25.5010			
1964	Replications	3	0.4903	0.1634	0.11	N.S.
	Fertilizer	3	11.0569	3.6856	2.38	N.S.
	Error	9	13.9538	1.5504		
	Total	15	81.3475			
1965	Replications	3	1.8917	0.6306	0.11	N.S.
	Fertilizer	3	28.1614	9.3871	1.65	N.S.
	Error	9	51.2944	5.6994		
	Total	15	46.8669			
1966	Replications	3	11.2685	3.7562	1.65	N.S.
	Fertilizer	3	15.1043	5.0348	2.21	N.S.
	Error	9	20.4141	2.2771		

Appendix 20

Analyses of variance of dry matter production from the early fall cut of "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1964	Total	15	25.6912			
	Replications	3	0.0815	0.0272	0.02	N.S.
	Fertilizer	3	9.6338	3.2113	1.81	N.S.
	Error	9	15.9759	1.7751		
1965	Total	15	27.5328			
	Replications	3	2.8554	0.9518	0.66	N.S.
	Fertilizer	3	11.6817	3.8939	2.70	N.S.
	Error	9	12.9957	1.4440		
1966	Total	15	9.1144			
	Replications	3	0.5532	0.1844	0.83	N.S.
	Fertilizer	3	6.5571	2.1857	9.81	1%
	Error	9	2.0041	0.2227		

Appendix 21

Analysis of variance of total dry matter production from "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	47	411.94			
Replications	3	17.23	5.743	0.34	N.S.
Fertilizer treatments	3	115.79	38.595	2.29	N.S.
Error I	9	151.98	16.889		
Years	2	58.24	29.122	10.74	1%
Replications x Years	6	9.29	1.548	0.57	N.S.
Fertilizer x Years	6	10.60	1.766	0.65	N.S.
Error II	18	48.82	2.712		

Appendix 22

Analyses of variance of crude protein production from the early summer cut of "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1964	Total	15	1.2462			
	Replications	3	0.0464	0.0153	0.22	N.S.
	Fertilizer	3	0.5606	0.1869	2.63	N.S.
	Error	9	0.6392	0.0710		
1965	Total	15	1.3580			
	Replications	3	0.0517	0.0172	0.17	N.S.
	Fertilizer	3	0.3919	0.1306	1.29	N.S.
	Error	9	0.9144	0.1016		
1966	Total	15	1.1598			
	Replications	3	0.2588	0.0863	2.33	N.S.
	Fertilizer	3	0.5675	0.1892	5.10	5%
	Error	9	0.3335	0.0371		

Appendix 23

Analyses of variance of crude protein production from the early fall cut of "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Year of Harvest	Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
1965	Total	15	0.2896			
	Replications	3	0.0465	0.0155	0.99	N.S.
	Fertilizer	3	0.1015	0.0338	2.15	N.S.
1966	Total	15	0.1444			
	Replications	3	0.0079	0.0026	1.04	N.S.
	Fertilizer	3	0.1137	0.0379	15.20	1%
	Error	9	0.0228	0.0025		

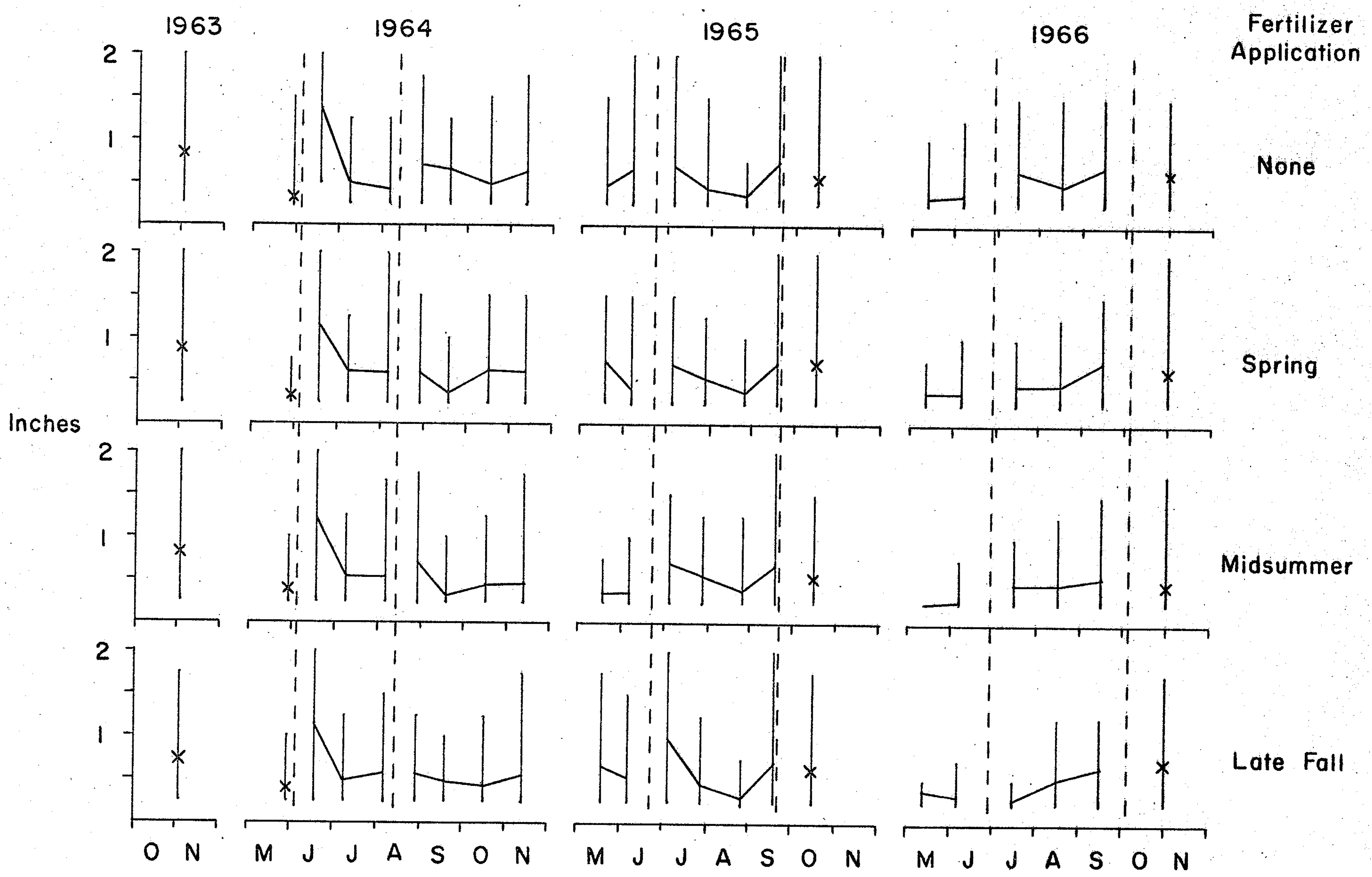
Appendix 24

Analysis of variance of total protein production from "Lincoln" bromegrass harvested for forage twice per year at Winnipeg

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Variance Ratio	Level of Significance
Total	47	9.0391			
Replications	3	0.4419	0.1473	0.49	N.S.
Fertilizer treatments	3	2.5054	0.8351	2.81	10%
Error I	9	2.6793	0.2977		
Years	2	2.1582	1.0791	18.57	1%
Replications x Years	6	0.1564	0.0261	0.45	N.S.
Fertilizer x Years	6	0.0525	0.0088	0.15	N.S.
Error II	18	1.0454	0.0581		

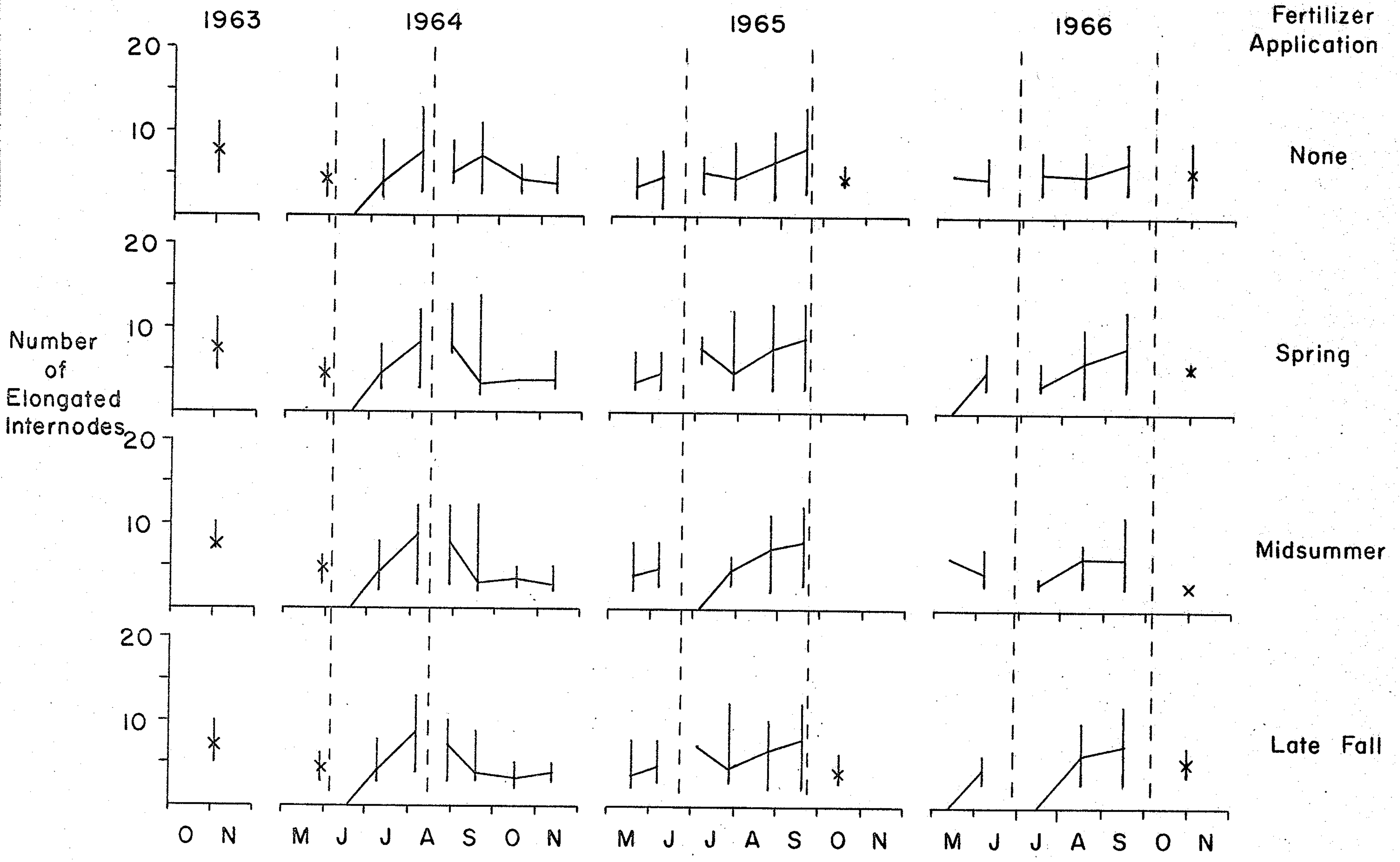
Appendix 25

Length of crown buds in bromegrass cut for forage twice per year



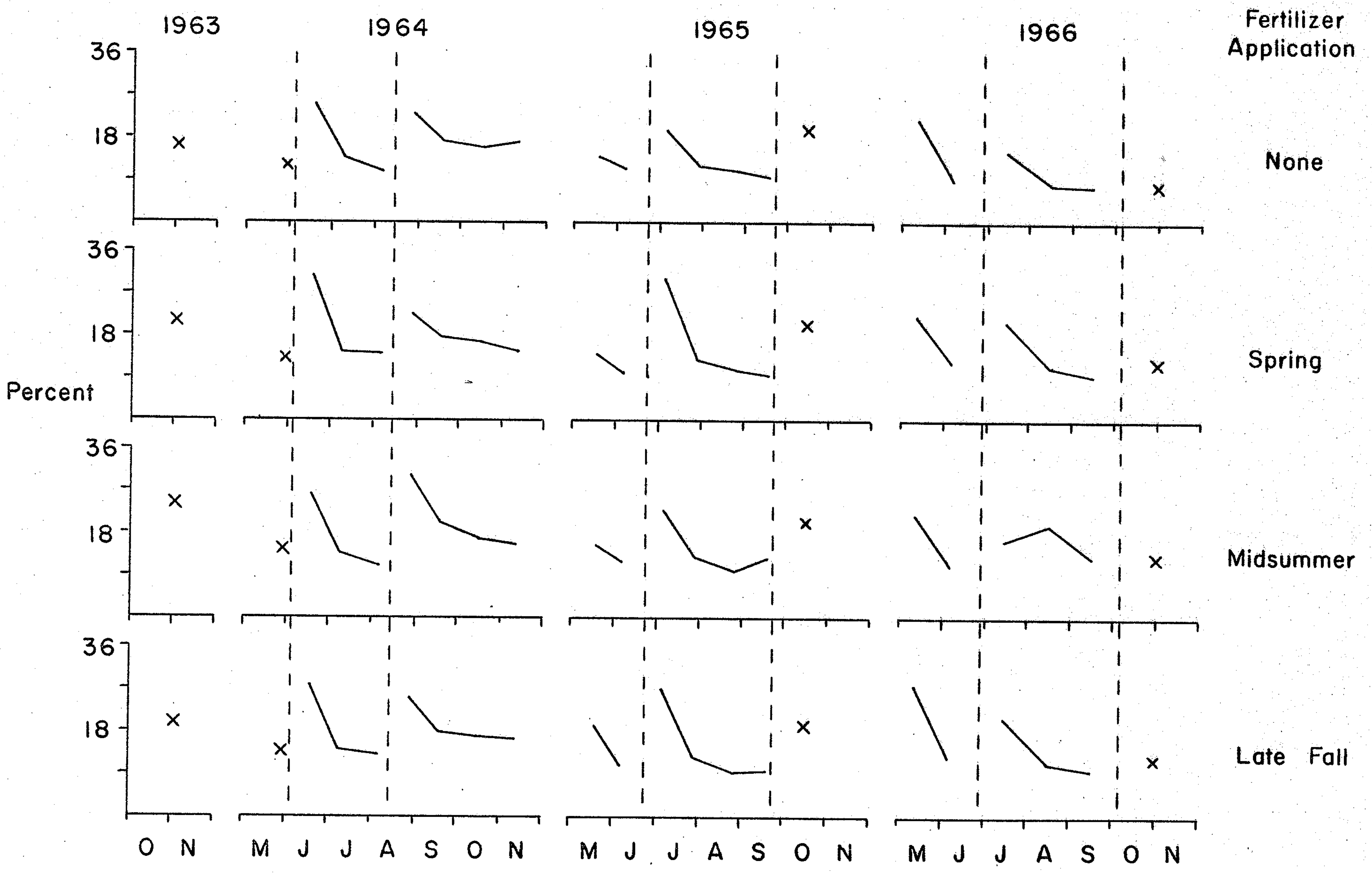
Appendix 26

Number of elongated internodes on sterile jointed tillers from bromegrass cut for forage twice per year

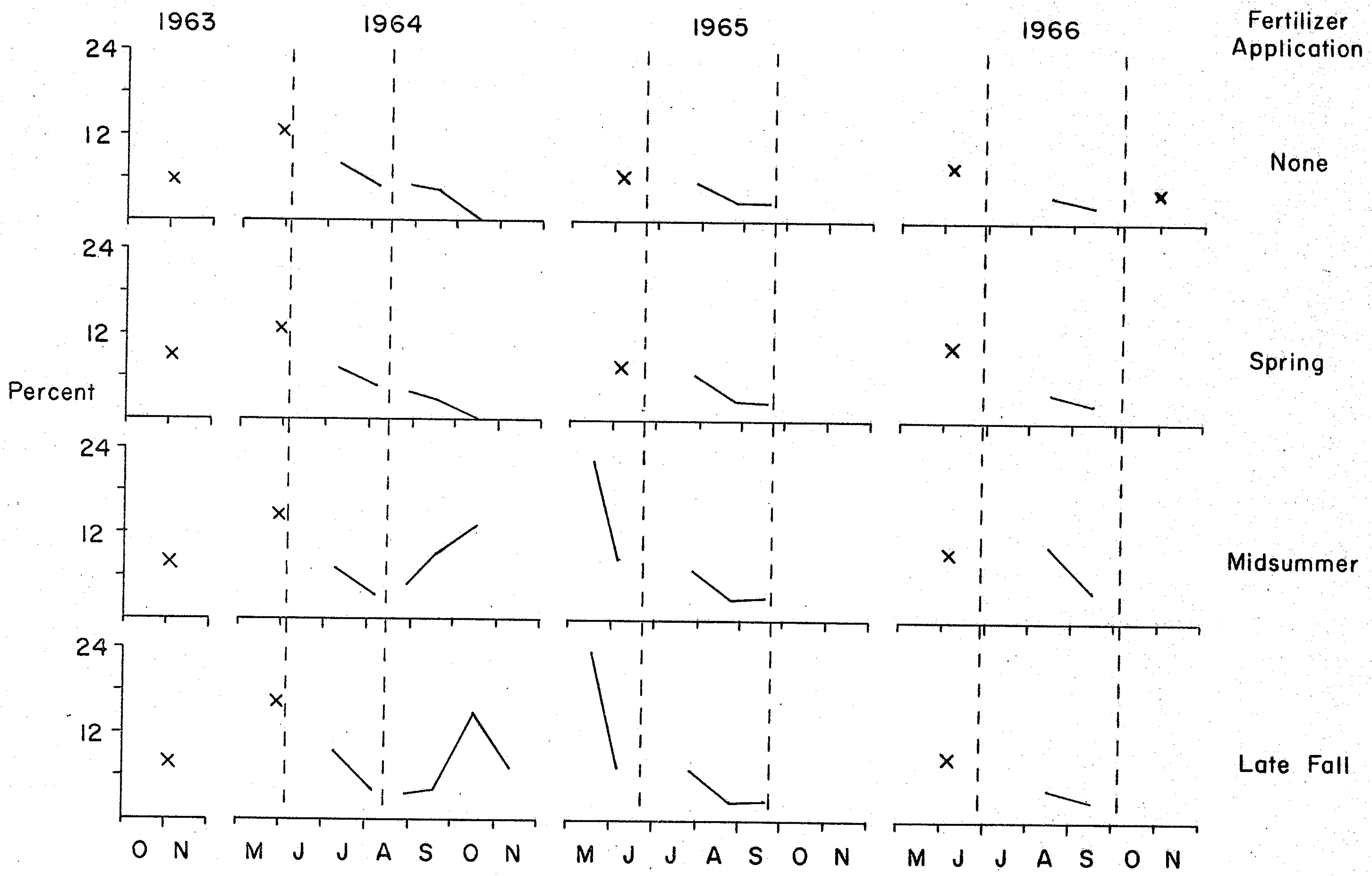


Appendix 27

Crude protein content of leaves from bromegrass cut for forage twice per year



Crude protein content of stems from bromegrass cut for forage twice per year



Appendix 29

Precipitation at the University of Manitoba during the fall of 1963 and the growing seasons of 1964 to 1966

Seven day period ending		Rainfall in inches			
		1963	1964	1965	1966
April	7		0	1.53	0
	14		0	0.90	0.10
	21		0	0.80	T#
	28		0	0	0.25
May	5		1.14	1.93	0
	12		0.20	0.22	T
	19		0.08	0.55	1.07
	26		0.08	0.94	0.28
June	2		0	0.98	T
	9		0.02	0.93	0.40
	16		0.44	0	0.95
	23		0.80	0.20	0.11
	30		0.46	1.49	0.62
July	7		0.50	1.47	3.22
	14		0.12	0.05	1.65
	21		0.05	1.60	0.71
	28		0.60	0.15	0.05
August	4		1.85	0.78	T
	11		0.72	0.03	1.02
	18		0.15	0.03	0.71
	25		1.54	0.60	T
September	1		2.44	0.62	4.03
	8	T	0.04	1.84	0.14
	15	0.33	0.13	0.23	0.30
	22	0.19	0.09	0.72	0
	29	0.38	0.46	0.08	0.23
October	6	0.03	0.08	T	0.15
	13	0	0	0.18	0.74
	20	0.60	0.05	0.51	0
	27	0.40	0	0.16	0.42

Trace of rain