CN 133

REGIONAL COPPER-NICKEL STUDY

SEASONAL VARIATIONS IN THE VEGETATION

Environmental Quality Board

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ABSTRACT

The relationship between phenologic events and physiological changes in the vegetation is reviewed in the light of its importance for wildlife and of the susceptibility of vegetation to pollution damage.

Phenological responses of eleven woody deciduous species were monitored by the Regional Study during the 1976 and 1977 seasons. Results of these observations are presented along with data on the temporal variation of 11 elements in forest species during the 1976 season and of 13 elements during the 1977 season.

Leaf-out in the region varies from mid-April to late-May, according to the species. Leaf-fall from deciduous species is complete by mid-October. Throughout the 1976 growing season, variations in foliar concentration of metabolically active elements such as P, K, Ca and Fe were greater than those of metabolically inactive elements such as Ni and Zn. Broadleaf deciduous species such as aspen and birch exhibited temporal variations in more elements than xeric conifers such as jack pine and red pine.

Background

Seasonal patterns in the vegetation, such as autumn color change, are physiological adaptations to the stresses of mid-continent, mid-latitude climatic conditions. For example, as winter approaches, water in the soil becomes unavailable to shallowly rooted plants creating conditions similar to drought. Both leaf-loss and needle-like leaves are adaptations to this condition. At the time of leaf-loss some elements are resorbed into the woody parts of the plant and others are lost to leaf litter, where decomposition may release them for use by other plants. As spring approaches and deciduous species re-equip themselves for photosynthesis by developing new leaves, the rising sap brings with it those elements that are vital to photosynthesis. Concentrations of elements vary throughout the plant and throughout the season. The changing appearance of the forest reflects its changing physiological state.

Phenological changes, such as bud swell, leaf-out, color change, and leaf fall, are important to the animal members of the community. The cover value of deciduous stands is reduced during the leafless season.

Browse value varies throughout the year not only in response to the presence or absence of leaves but according to the distribution of elements within the plant. Tew (1970) studied the seasonal variation in nutrient content of aspen leaves in Utah. Ca, Na, Mg and fat in leaves increased as the season progressed, whereas N, P, and K decreased. Smirnov and Semenova (1973) report an initial reduction of Ca and P from late May to June in leaves of aspen and birch with an additional reduction of P and K at the end of the season. Such reduction in foliar content of P and K suggests that these elements are translocated from the leaves back into the plant, whereas Ca may be lost from the plant into the litter.

Huff (1973) found similar trends in elemental content of aspen foliage in Minnesota. In his study crude protein followed the trend in potassium, sodium and copper, and decreased throughout the summer; wheras fat concentration, ash content, Ca, Fe, Mg, Mn and Zn increased. He noted that "progressive changes in nutrient levels through the summer may influence grouse to seek foods of higher protein value when levels are reduced to a certain 'critical' level. Localized fluctuations in aspen nutrient levels may influence grouse to vary diets at different times in different years."

In addition to changes in the nutrient value of the plant, phenological patterns may have secondary effects on dependent animals. Songbirds dependent on foliage-feeding insect grubs or on fruits that take time to develop can be expected to delay their arrival until these resources are available.

The relationships between phenological patterns and potential impacts of copper-nickel mining are at least threefold.

Most obvious of potential relationships is the possibility of mistaking symptoms of acute pollution injury for premature phenological changes. Chlorosis (yellowing of the leaves) is the dominant symptom of acute SO_2 injury and of excess nickel uptake (Guderian 1977; Tamm and

Aronsson, 1972). Unless normal dates of color change are known for an area, premature yellowing might be attributed to an early autumn. Such premature leaf senescence, as well as premature abcission, has been reported in deciduous species near a nickel smelter in Thompson, Manitoba (Blauel and Hocking, 1974). Evergreen species in that area (black spruce and jack pine) retained their needles for only one or two years.

More important than the possibility that symptoms of injury may be confused with normal changes are differences in susceptibility at different phenological stages. Contrary to early reports (Zimmerman and Crocker, 1934), newly emerged leaves of deciduous species are apparently more resistant to SO_2 damage than fully developed leaves. Tamm and Aronsson (1972) report studies by Van Haut (1961) in which the most photosynthetically active leaves are most susceptible to injury. Van Haut attributes the apparent resistance of the youthful leaves to the fact that their stomata are not yet fully functioning. On the other hand, Guderian (1977) suggests that even in comparison with the amount of S accumulated, the younger leaves are resistant. The resistance is manifested in reduced leaf injury under long term exposures at low concentrations. The mechanism of protection for the youngest conifer needles is suggested in a study by Caput, Benot, Auclair and Decourt (1978). Very young needles, less than a month old, developed necrosis only on the part of the needle already emerged from the basal sheath. Portions of the needles protected by the sheath at the time of exposure developed normally. The physical protection of the sheath, rather than any special resistance, appears to be the mechanism of protection because exposures of 2 $\mu g/cm^2$ produced injury in exposed parts of young needles, whereas in mature needles 5 $\mu g/cm^2$ were needed to cause the same injuries.

The practical effect of varying sensitivities at different stages of development is illustrated in table 1, from Driesinger and McGovern (1970). Only 2% of potentially injurious fumigations occurring in the Sudbury area in May 1964-1968 resulted in injury to vegetation, whereas 55% of midsummer 1964-1968 fumigations caused injury.

In addition to differing susceptibilities at different stages of leaf development, Karnovsky (1975) found that the stage of development of staminate and pistillate flowers of aspen affects the influence of pollutants on reproduction.

Concentrations of sulphur (Lehnell, 1969; Karnovsky, 1975) and of metals (Whitby et al., 1976; Lev et al. 1975) in foliage have been used to measure the impacts of pollution. Without an understanding of the normal range of values and seasonal trends in elemental concentration, such methods of monitoring are of limited value. Guha and Mitchell (1966) suggest that the only elements that can be used for diagnostic purposes are those that exhibit a period of constant concentrations during the midsummer. In studies using beech, horse-chestnut, and sycamore they found that the following elements exhibited this pattern: Cu, Mo, Zn, P, K and Na.
The variability between species suggests the need for baseline studies to identify appropriate elements for diagnostic use on many available species.

spectography at monthly intervals during June, July, August, and September. Similar data were obtained for 9 species the months of May, July, and September during the 1977 field season. Pooled samples from 12 individuals of a species at each site were analyzed by neutron activation analysis for 13 elements in 1977.

Results

Phenological Responses

The date of initial activity for each of the four phenological responses is shown for each species in table 2. Species are arranged in order of first phenological activity during the 1976 and 1977 seasons. In some species the first activity was flowering and in others it was leaf-out.

The date of initial leaf-out varied from April 20 for tamarack in 1977 to May 29 for black ash in 1976. Trembling aspen was the first broadleaf species to leaf. The small sample size for most species and the within-site variability make it difficult to document the obvious lag time of several days between leaf-out in the southern and northern parts of the area.

Figures 1 through 12 illustrate the phenological patterns for each species for the two years. Phenological patterns differed between the two study seasons. Because the 1976 observations were begun in May and both spring weather and phenological responses were unusual during that year, differences in spring responses between the two years cannot be explained. For example, species that apparently did not flower in 1976 may have flowered before observations began.

Methods

Phenological responses of eleven species of deciduous woody plants were monitored by the Regional Copper-Nickel Study during the 1976 and 1977 field reasons. Four hundred seventeen individuals of these species were observed: trembling aspen (Populus tremuloides), balsam poplar (Populus balsamifera), large-toothed aspen (Populus grandidentata), black ash (Fraxinus nigra), tamarack (Larix laricina), paper birch (Betula papyrifera), green alder (Alnus crispa), speckled alder (Alnus rugosa), beaked hazel (Corylus cornuta), red osier dogwood (Cornus stolonifera), and mountain maple (Acer spicatum).

Observation stations were established at 1.8 mile intervals with 10 sites north and 10 sites south of the Laurentian divide in hopes of observing variations in phenological response along a latitudinal gradient. Wherever possible, an attempt was made to observe 10 individuals of each species at each site. Data were recorded as percent of flower development, leaf out, color change, or leaf-fall on each tree of each species. Observations were made once or twice a week from mid-April (1977) or mid-May (1976) to the end of May and from mid-August through October (both years).

In addition to observations of phenological responses at the beginning and end of the growing season, temporal variations in foliar concentrations of 13 elements were monitored in 11 species during the 1976 season. Pooled samples from 12 individuals of a species from each of 22 plant pathology study sites were analyzed by atomic absorption

Bimodal distributions of flowering time were observed in large-toothed aspen (Populus grandidentata, Figure 10). This distribution was caused by earlier flowering of staminate flowers. Such earlier flowering of male plants has been observed in forced materials (USFS, 1974). The smaller size of the later curve is explained by the disproportionate number of male to female trees in the study plots (7:3)

Leaf color change in most species began about two weeks earlier but leaves of several species persisted longer during the drier 1976 season. Anomalous behavior in 1976 is explained by the fact that many leaves wilted and turned brown in late August without forming abcission layers. These wilted leaves persisted later into the autumn than leaves that underwent normal color change. Hazel (Corylus cornuta) and trembling aspen (Populus tremuloides) were the species most seriously affected. In both years, tamarack changed color about three weeks later than most other species.

A five-year study of the phenology of seventeen tree species near Basswood Lake north of Ely (Ahlgren, 1957) provides a more detailed background with respect to seasonal changes in the vegetation in northeastern Minnesota. Ahlgren found that annual variations in phenological responses were correlated with variable environmental influences such as temperature and rainfall rather than those that remain stable from year to year, such as photoperiod and light intensity. Bud swell in several species was correlated with temperature thresholds, but leaf-out was not correlated with current temperature levels for any of the species. Species whose bud-swell correlated with temperature thresholds were black ash (*Fraxinus nigra*), mountain ash (*Sorbus americana*), paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*)and white pine (*Pinus strobus*). Staminate flower development in birch occurred at the same time as bud swell and was often initiated in cool weather when maximum temperatures were below 65°F and minima were below freezing. Our data (Table 2 and Figure 13) show a similar pattern of flower development for birch, although minimum temperatures in 1976 and 1977 were not below freezing.

The relationship of flowering times to vegetative developments within species followed consistent patterns over the five years of Ahlgren's study. Ahlgren reports four broad patterns in the sequence of blooming and vegetative activities.

1. Flowering preceded vegetative bud swell in silver maple (*Acer saccharinum*), red maple (*Acer rubrum*), and white cedar (*Thuja occidentalis*). None of these species was observed as part of the Regional Copper-Nickel study phenology survey. Because bud swell was not recorded in our survey, there is no way of knowing whether those species that flowered before leaf-out during the 1976 and 1977 seasons actually flowered before or during bud swell. These species are discussed in more detail below.

2. Ahlgren found that flowering always followed vegetative bud swell but preceded leaf-out in black ash, white spruce, black spruce, balsam fir, white pine, and red pine. 1977 data for the Copper-Nickel area show that flowering preceded

leaf-out in black ash by two to three weeks. None of the evergreens in Ahlgren's sample were included in the Copper-Nickel Study phenology survey.

3. In Ahlgren's study, flowering followed leaf-out in bur oak (_Quercus macrocarpa_), basswood (_Tilia americana_), mountain ash, and tamarack. 1977 data for the Copper-Nickel area confirm this pattern for tamarack, with a two week lage between initial leafing and initial flowering.

4. Several of Ahlgren's species flowered simultaneously with vegetative bud swell. Species exhibiting this pattern between 1951 and 1956 were trembling aspen, large-toothed aspen, paper birth, yellow birch (_Betula lutea_), red ash (_Fraxinus pensylvanica_), and American elm (_Ulmus americana_). Although bud-swell was not observed as part of the Copper-Nickel phenology survey, it appears that the pattern of flowering before leafing in paper birch, large toothed aspen, and trembling aspen was probably during bud swell (Figures 3, 10, and 2). Speckled alder (_Cornus rugosa_) and hazel (_Corylus cornuta_), two shrubs in the birch family, appear to have followed the same pattern in 1977.

Elemental concentration of foliage

Elemental concentration of foliage does not necessarily reflect the concentration of the element throughout the plant because certain elements are known to concentrate in certain parts of the plant (Patterson 1976; Saenko _et al_., 1968).

For example, whereas nickel is labile and is likely to be translocated to the leaves even though it is not needed for photosynthesis, copper is likely to be retained in the roots (Saenko *et al.*, 1968). Nonetheless, foliar concentrations are most often used in studies that monitor pollution effects without knowledge of the range of seasonal variations, and values that are part of the normal range of seasonal variability could be interpreted as abnormal values. The data presented in this report are of a preliminary nature and suggest the sorts of variations and trends that may occur throughout the season. Neither the duration of sampling, sample size, or number of replicates is sufficient to establish "normal" baseline values for the area.

Seasonal variations in elemental content of foliage vary both between elements and between species. In most cases fluctuations for a single element do not show the same trend for all species, nor do fluctuations within a species show the same trend for all elements.

1976 data (figures 14-24) are discussed separately from 1977 data (figures 25-34) because of the difference in sampling intervals, sampling methods, and methods of analysis between the two years. Although these differences in methodology do not permit direct comparison of measured values between the two years, it is possible to detect patterns of foliar elemental content within each season. The point for a given species on a given date in figures 14-34 may represent a single sample or the average of several samples (maximum, n=9).

In 1976, P and Fe are highest in almost all species in June and drop in July, thereafter either levelling off (P) or rising in early autumn (Fe).

Phosphorus follows the same trend in the 1977 data (figure 25), but Fe (figure 26) shows a rise from May 17 to July 30, followed by a drop. Some of the difference may be accounted for by the fact that 1976 sampling concentrated on coniferous canopy species whereas 1977 sampling emphasized understory shrubs and herbs, but this argument cannot be used to explain the wide discrepencies in average values for the 2 species that were sampled in both years. These differences may or may not result from differences in sampling and analytical procedures between the two years. An alternative explanation for the divergent results may be that different trees at different sites were sampled in the two years. Although 1976 data for Fe tend to follow the pattern reported by Guha and Mitchell (1966) for beech, sycamore, and horse chestnut, 1977 data suggest that Fe values are unpredictable and depend on the individual species being sampled, whereas P follows a pattern similar to that reported in the literature (Tew, 1970, Guha and Mitchell, 1966) during both years.

1976 data suggests that K content of needle-leaf conifers is conservative over the season, whereas that of deciduous trees and grass is higher initially and falls at the time of color change. A similar decline in K content over the season occurs in aspen and beaked hazel in 1977. Such a decline agrees with that reported in the literature (Tew, 1970, Guha and Mitchell, 1966).

1977 data show an overall rise in Ca over the season for all species (figure 28) but 1976 data are more erratic (figure 23). In both years Ca variation in aspen leaves is consistent with the late summer rise reported in the literature (Smirnov and Semenova, 1973; Tew, 1970).

In both years Ca values were still high at the time of initial color change and leaf-fall, suggesting that Ca is returned to the litter layer in aspen stands. Data for black spruce for the two years are contradictory and no general conclusions can be drawn from them.

Data for Mg are only available for 1977 (figure 29). This element appears to behave quite differently in the different plant species and to show no general overall trend.

Because of its importance as an indicator of pollution, the S content of foliage is often monitored as a measure of impacts (Lihnell, 1969; Karnovsky, 1975; Guderian, 1977). Entry of sulphur-dioxide into plants is dependent on stomatal activity and is therefore most likely during periods of active photosynthesis. This relationship between SO_2 gas exchange and photosynthesis is the basis for higher susceptibility of plants to SO_2 injury during midsummer months. 1976 data from the Study Area (without the influence of SO_2 fumigation) show a midsummer rise in the S content of all needle-leaf conifers except cedar (figure 17). White pine, the pine most susceptible to SO_2 damage (Driesinger and McGovern, 1970; Linzon, 1966) not only shows higher midsummer levels of S, but a greater seasonal variation than red and jack pine. On the other hand aspen, grass, and birch demonstrate a decline in S content over the season. As is the case with any such declining value, it must be noted that initial concentrations may appear higher because leaves are smaller in the spring. Although the increase in leaf biomass over the season is not known, it is unlikely that such drastic changes as those in aspen and grass are merely the result of leaf growth. No data for S concentration are available for the 1977 season.

1977 data (figure 30) appear to suggest that Mn rises in most species over the season. On the other hand 1976 data (figure 24) for all species except the spruces and fir contradict this interpretation. Although the changes differ in direction, seasonal variations in aspen are very small during both seasons.

The remaining elements are all metals that could be expected to increase in the environs of copper-nickel mining operations. Of these, copper decreased over the season in all deciduous species during both years (figures 18 and 31) in keeping with the trend reported by Guha and Mitchell (1966) for beech, sycamore and horse chestnut. The behavior of copper in needle-leaf evergreens was more conservative, generally showing a slight decline between June and July (1976), followed by a slight rise in most species. Such a rise in black spruce did not occur at the end of the 1977 season, although the mid-September value (3 ppm) was similar to late-August values in 1976.

Zinc appears to be present in the foliage of most species at concentrations between 20 and 80 ppm and does not vary much throughout the season (figures 19 and 32). During the 1977 season an initial drop in Zn content of most species was followed by a slight rise in foliar content. In large-leaved aster and false-solomon's seal the rise was abrupt and on the order of 30 ppm. The seasonal behavior of Zn in aspen differed between the two years. 1976 data suggest that Zn is very conservative in aspen, but 1977 data show an increase from 110 ppm in late July to

187 ppm in mid-September. The final value is nearer the range of Zn values in aspen in the 1976 data.

Nickel concentrations are known only for the 1976 season, when this reputedly labile element remained very constant at levels between .5 and 4 ppm in all species (figure 21).

The behavior of Al (figure 33) and Cr (figure 34) in leatherleaf appears to differ markedly from their seasonal patterns in the other species that were sampled. Values of Al in leatherleaf are so high that they suggest differential concentration of the element by this plant. In general, 1977 data suggest a midsummer peak in Al for most species and a similar peak in Cr in hazel, false solomon's seal, and sedge. No 1976 data are available for these 2 elements.

The lead content of foliage has been used to assess the extent of pollution along roadsides (Hemphill, 1974) as well as to measure the impact of smelters (Lev et al. 1975). Much of the lead from these sources is of a particulate nature. 1976 data (figure 22) show consistently lower levels of Pb at the beginning of the season than later. In white spruce, tamarack, and cedar levels were continuing to rise at the end of the season, whereas in the other species levels had begun to decline by the last sampling date. The coincidence of declining Pb in foliage and color change in aspen may suggest that at least part of the lead is being translocated back into the woody parts of the tree rather than discarded with the leaves. No data are available for Pb during the 1977 season.

Discussion

The results presented here suggest the potential for understanding the dynamics of elemental variation and seasonal pattern in forested communities. However, interpretation of the data is limited by the infrequency of sampling and, most especially, by the lack of information about growth of leaves. Apparent decreases in elemental concentration over the growing season may result from an increased biomass of leaf with the same absolute amount of the element or they may reflect real changes. An ongoing program of phenological observation and monitoring of foliar composition could be made more complete by extending the season for foliar analysis at both ends, continuing phenological observations throughout the summer to include some index of leaf growth (direct measurements, weight increase, or leaf area index) and sampling of the fresh litter for elemental composition.

Table 1. Frequency of occurrence of injury to vegetation near ten SO_2 autometer sites following potentially injurious fumigation (P.I.F.) recorded between 1964 and 1968 inclusive

	Total No. of P.I.F.	No Injury	One or More Species Injured		Total No. of P.I.F.	No Injury	One or More Species Injured		Total No. of P.I.F.	No Injury	One or More Species Injured	
		-May-		% of all PIF in month		-June-		% of all PIF in month		-July-		% of all PIF in month
Garson	12	12	0	2%	19	12	7	55%	15	5	10	56%
Skead	11	11	0		24	14	10		15	11	4	
Kukagami	1	1	0		2	1	1		1	0	1	
Grassy	0	0	0		0	0	0		0	0	0	
Penage	1	1	0		4	2	2		1	0	1	
Morgan	3	3	0		0	9	0		2	0	2	
Burwash	0	0	0		1	1	0		0	0	0	
Rayside	10	9	1		2	1	1		4	1	3	
St. Charles	0	0	0		0	0	0		0	0	0	
Callum	4	4	0		4	0	4		1	0	1	
Total	42	41	1		56	31	25		39	17	22	
		-Aug-		% of all PIF in month		-Sept-		% of all PIF in month		-Oct-		% of all PIF in month
Garson	12	10	2	24%	6	6	0	10%	6	6	0	0%
Skead	12	11	1		15	13	2		13	13	0	
Kukagami	1	1	0		2	2	0		4	4	0	
Grassy	0	0	0		0	0	0		0	0	0	
Penage	5	1	4		2	2	0		2	2	0	
Morgan	0	0	0		1	1	0		2	2	0	
Burwash	0	0	0		0	0	0		0	9	0	
Rayside	4	3	1		8	7	1		2	2	0	
St. Charles	0	0	0		0	0	0		1	1	0	
Callum	7	5	2		4	3	1		1	1	0	
Total	41	31	10		38	34	4		31	31	0	

Table 2. Initial dates of major phenological activities. Species are listed in order of first activity. Copper-Nickel Study results include 1976 dates (month/day) in the upper row and 1977 dates in the lower row. Dates from Ahlgren (1957) are the earliest recorded date of activity (upper row) and latest recorded date of activity (lower row). Where only one date is shown for results of the Copper-Nickel Study, only one year's observations are available. Spring dates record initiation of activity, fall dates record completion.

	REGIONAL COPPER-NICKEL				AHLGREN 1957			
SPECIES	Flower	Leaf	Color	Fall	Flower	Leaf	Color	Fall
Trembling aspen		5/7	10/22	10/22	4/14	9/26	10/4	
Populus tremuloides	4/3	4/28	10/7	10/14	4/24	5/21	10/4	10/14
Speckled alder			10/8	10/15				
Alnus Rugosa	4/13	5/5	10/14	10/13				
Large-toothed aspen		5/25	10/8	10/22	4/23	5/19	9/20	10/4
Populus grandidentata	4/14	5/15	9/30	10/7	5/15	6/8	10/4	10/14
Hazel			10/8	10/22				
Corylus cornuta	4/17	5/3	9/16	9/16				
Tamarack			10/8	10/22	4/25	4/21	10/6	10/8
Laria laricina	5/4	4/20	10/7	10/7	5/9	5/16	10/10	10/18
Paper birch		5/15	10/1	10/11	4/2	4/29	9/16	9/26
Betula papyrifera	4/30	5/8	9/23	9/30	4/23	5/21	9/26	10/10
Balsam poplar		5/15	10/8	10/22				
Populus balsamifera	5/3	5/3	9/30	10/7				
Black ash		5/29	9/17	9/24	4/27	5/20	8/29	9/19
Fraxinus nigra	5/6	5/19	9/11	9/2	5/25	6/8	9/13	10/3
Red Osier dogwood			10/1	10/15				
Cornus stolonifera	5/27	5/6	10/7	9/30				
Green alder		5/16	10/22	10/22				
Alnus crispa	5/6	5/11	10/14	10/12				
Mountain maple		5/14	10/1	10/22				
Acer spicatum	5/27	5/9	9/30	9/30				

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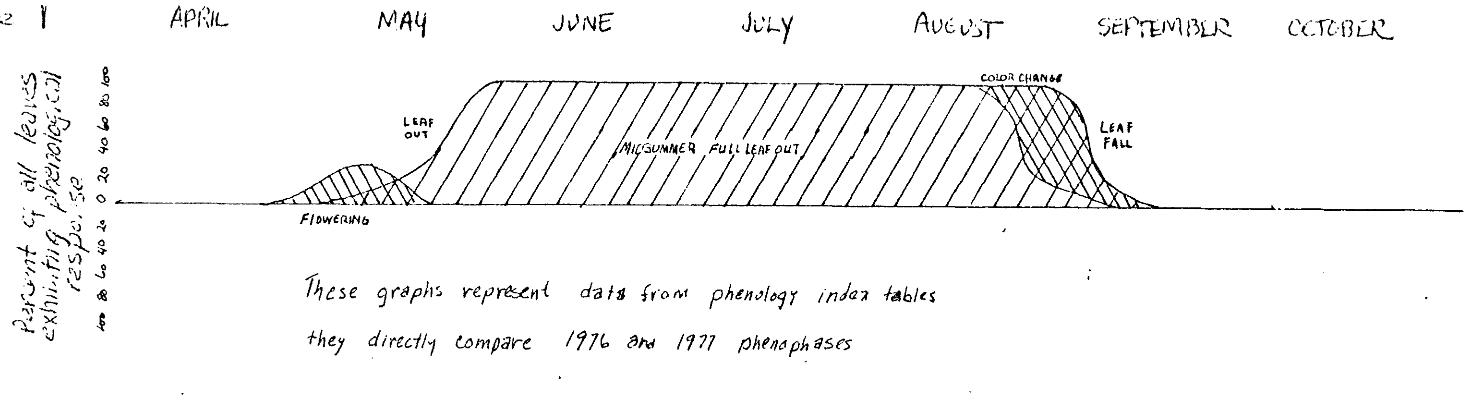
FIGURES 1-12 PHENOLOGICAL PATTERNS OF DECIDUOUS SPECIES

Figure 1



These graphs represent data from phenology index tables

they directly compare 1976 and 1977 phenophases

Figure 2

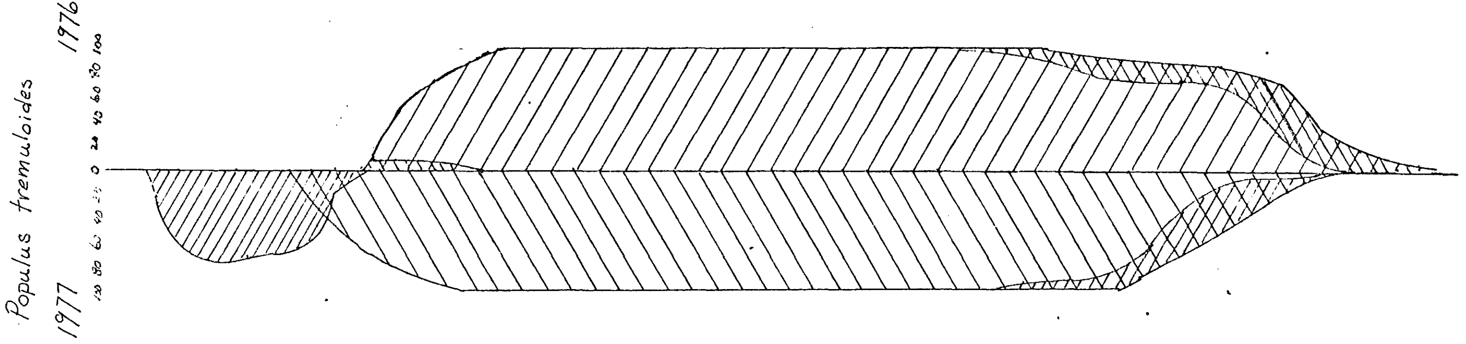


Figure 3

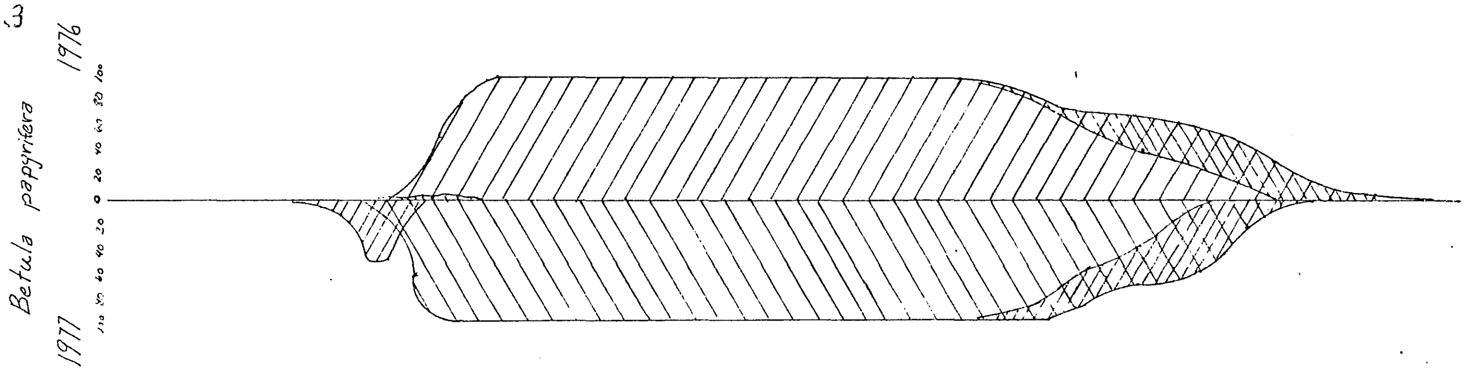


Figure 4

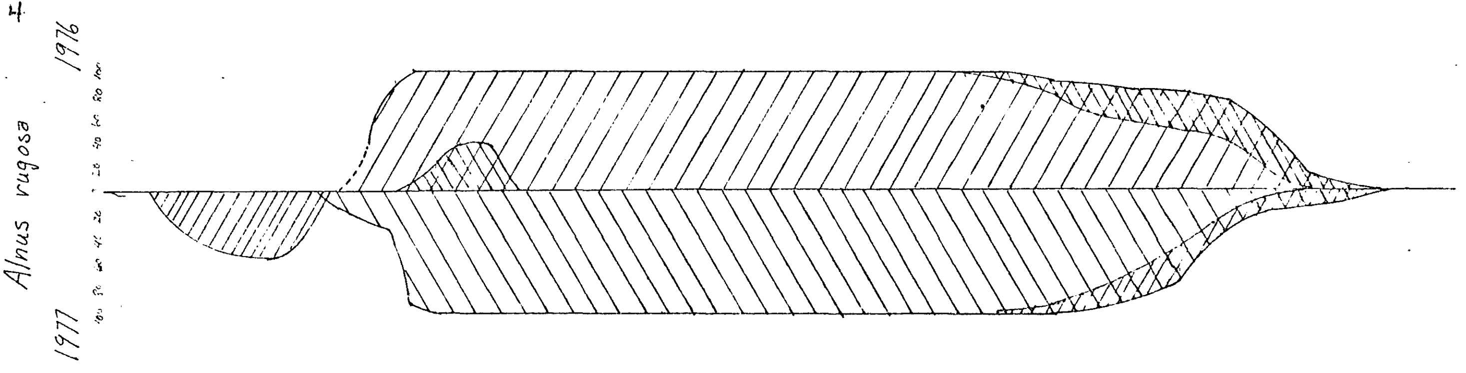
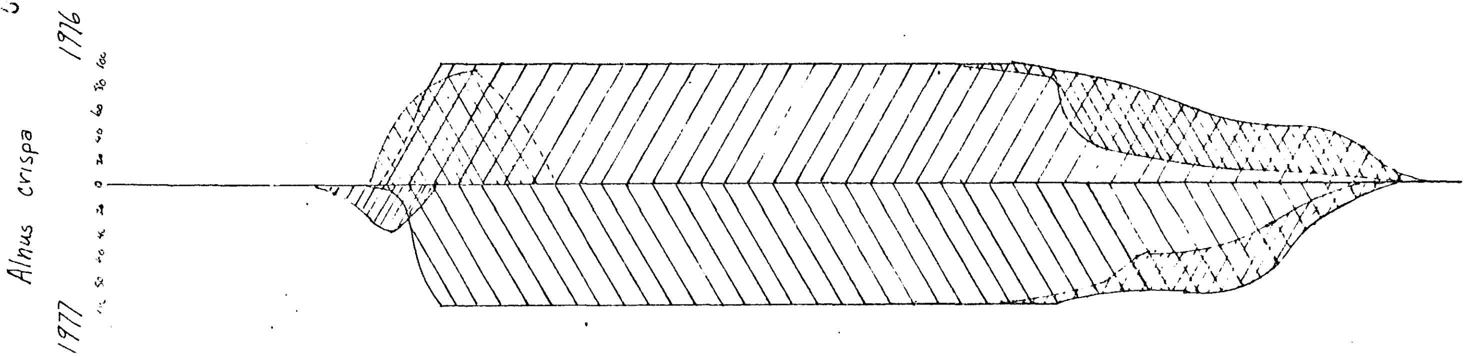


Figure 5



APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER

Figure 6

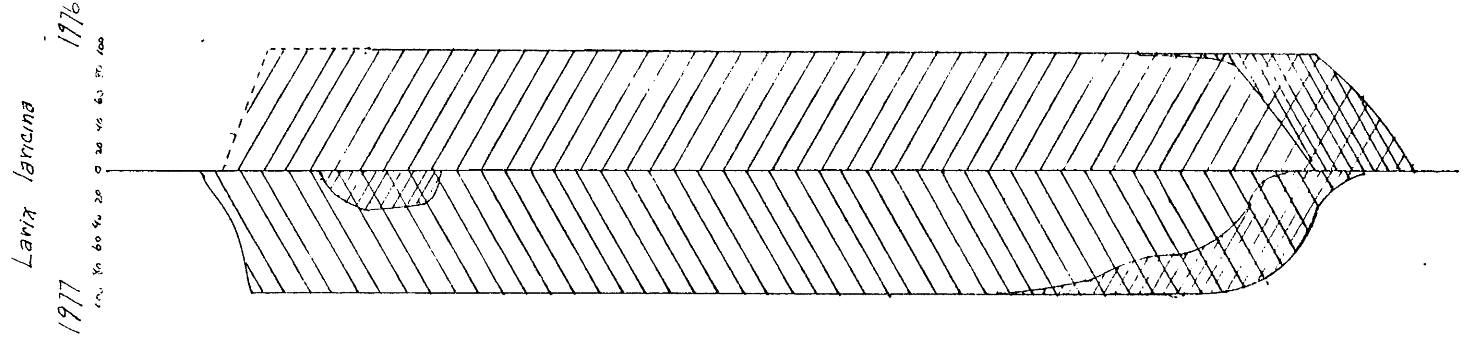


Figure 7

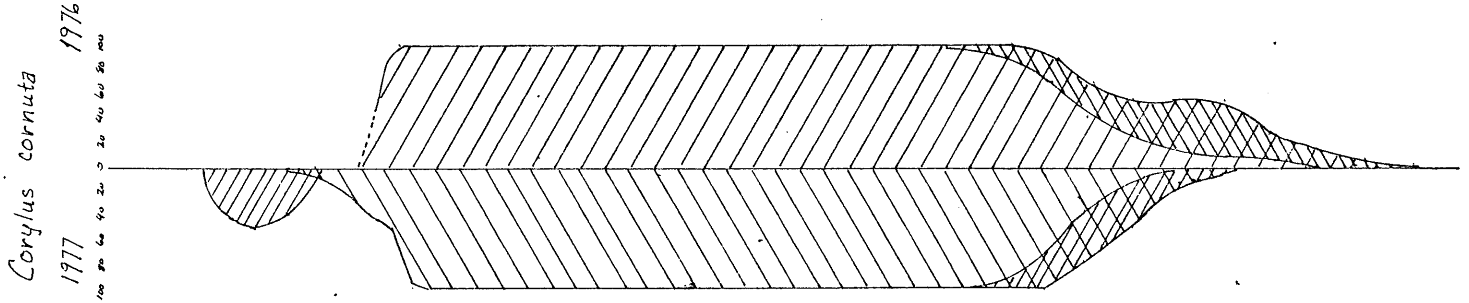


Figure 8

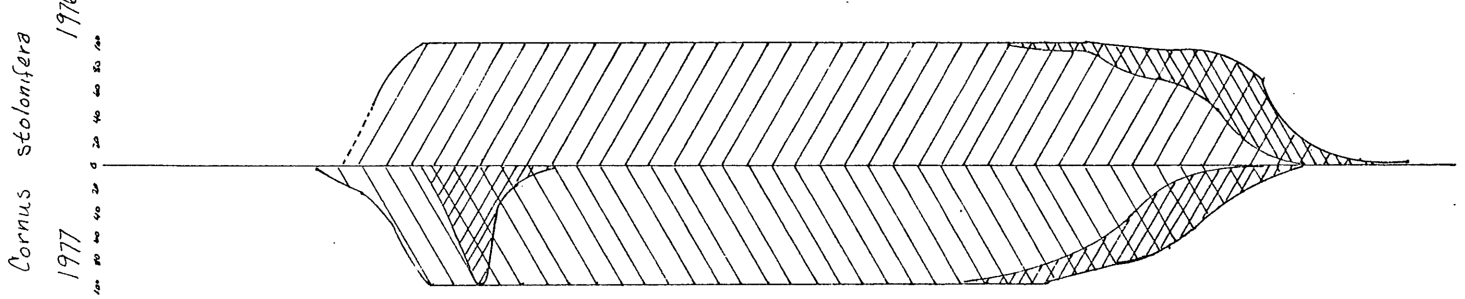


Figure 9

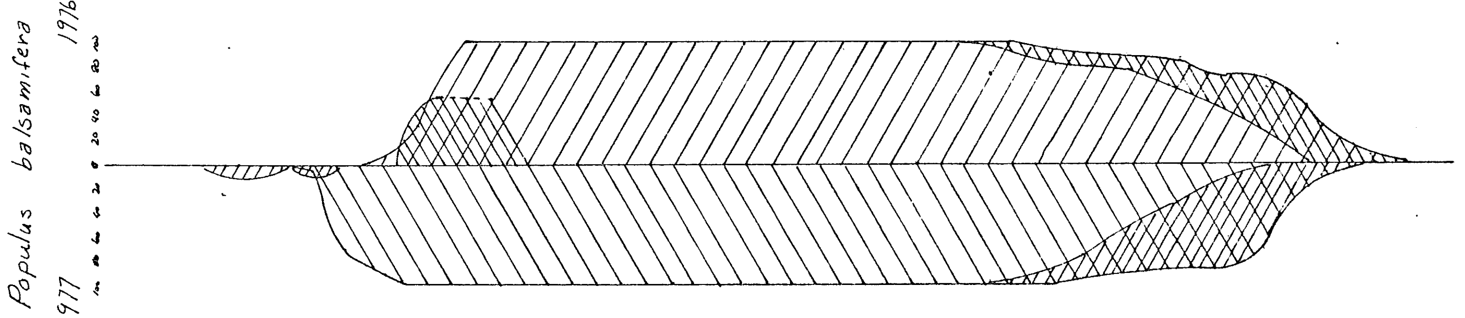


Figure 10

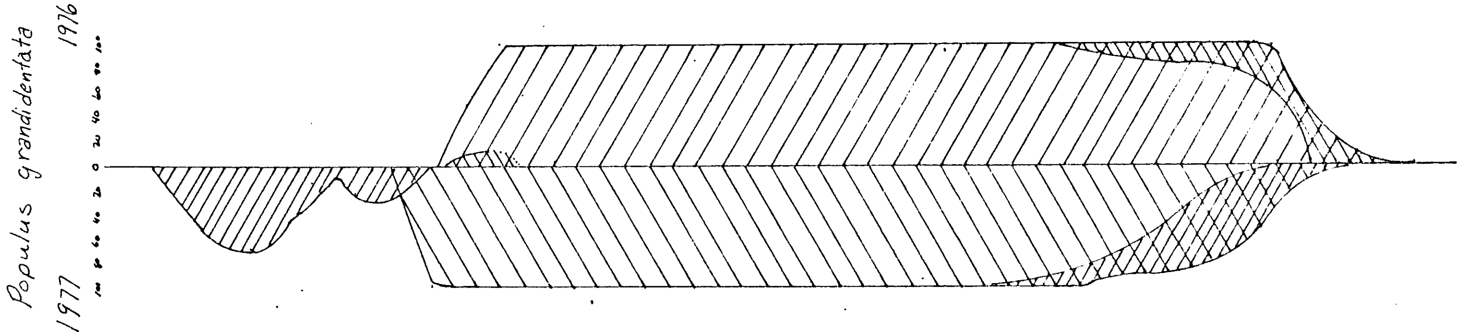


Figure 11

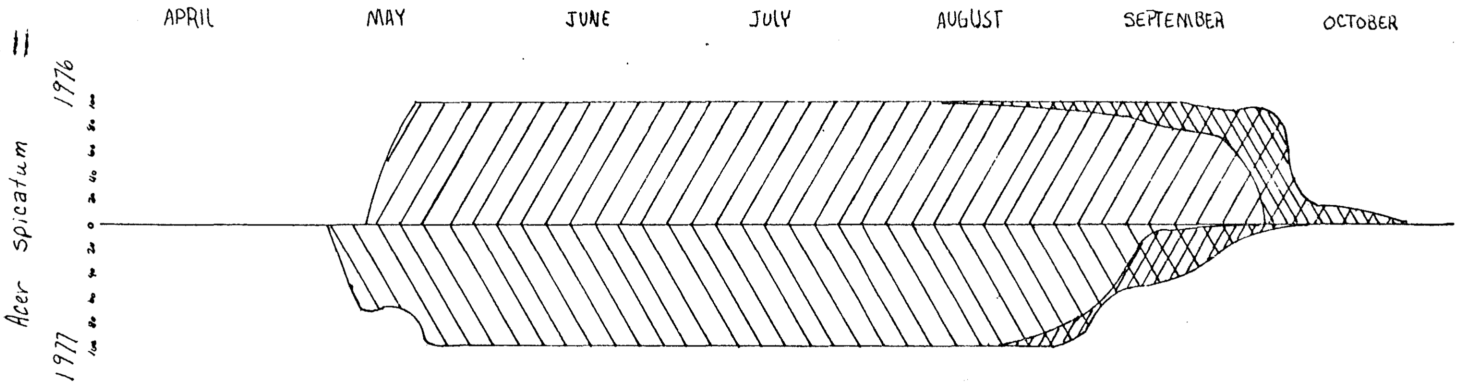
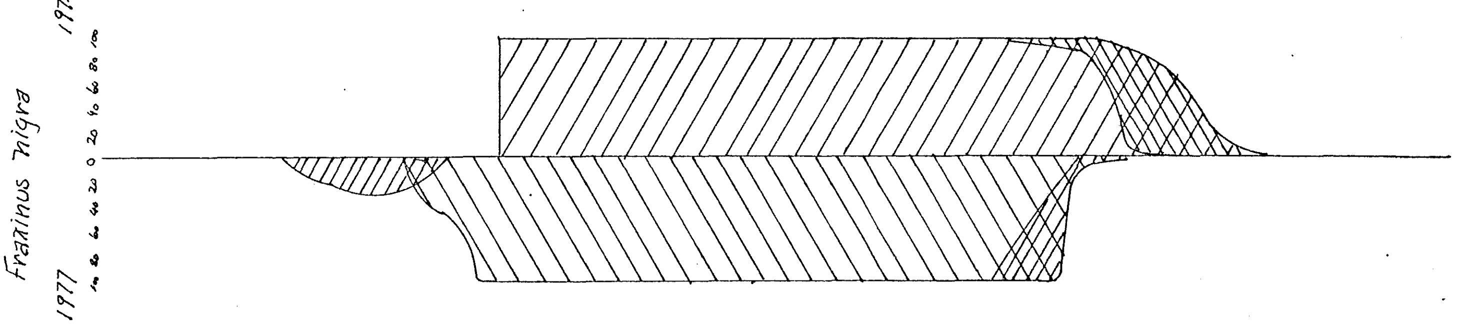


Figure 12



1976

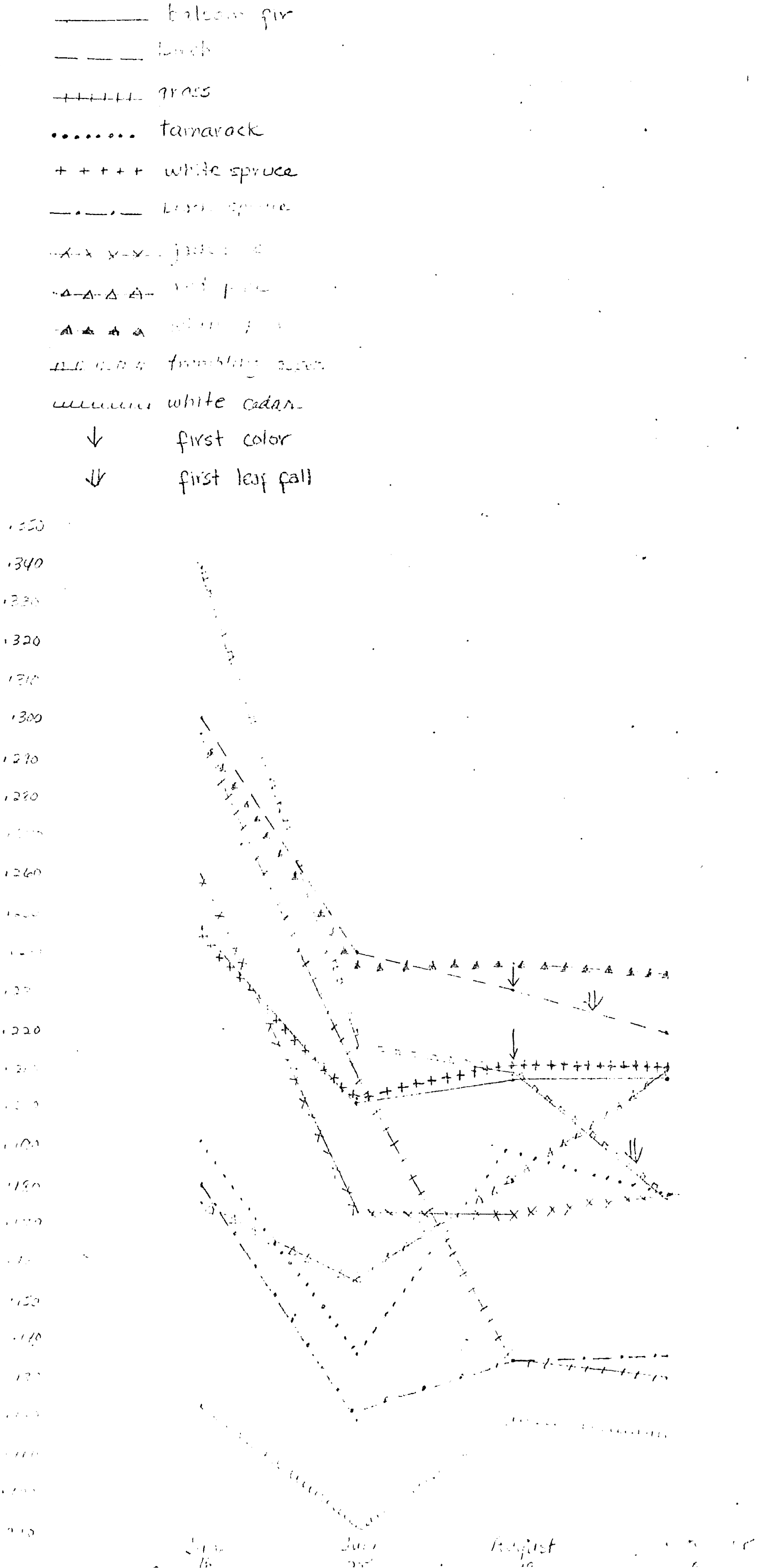
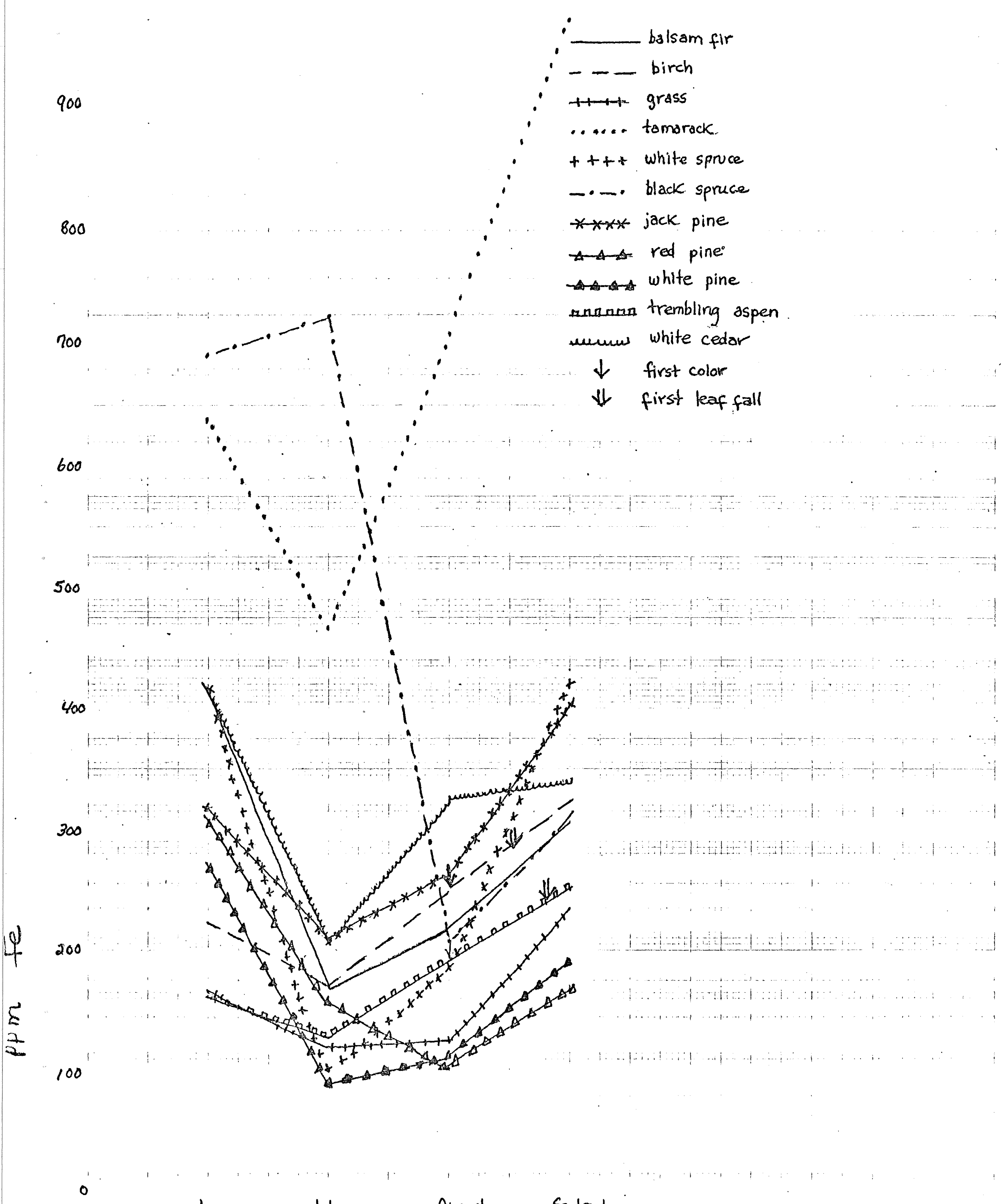

balsam fir
birch
grass
tamarack
white spruce
trembling aspen
white cedar
↓ first color
⇓ first leaf fall
.340
.320
.300
.290
.280
.260
.220
August

Figure 15 Seasonal variations in iron content of foliage, 1976



Seasonal variations in potassium content of foliage, 1976

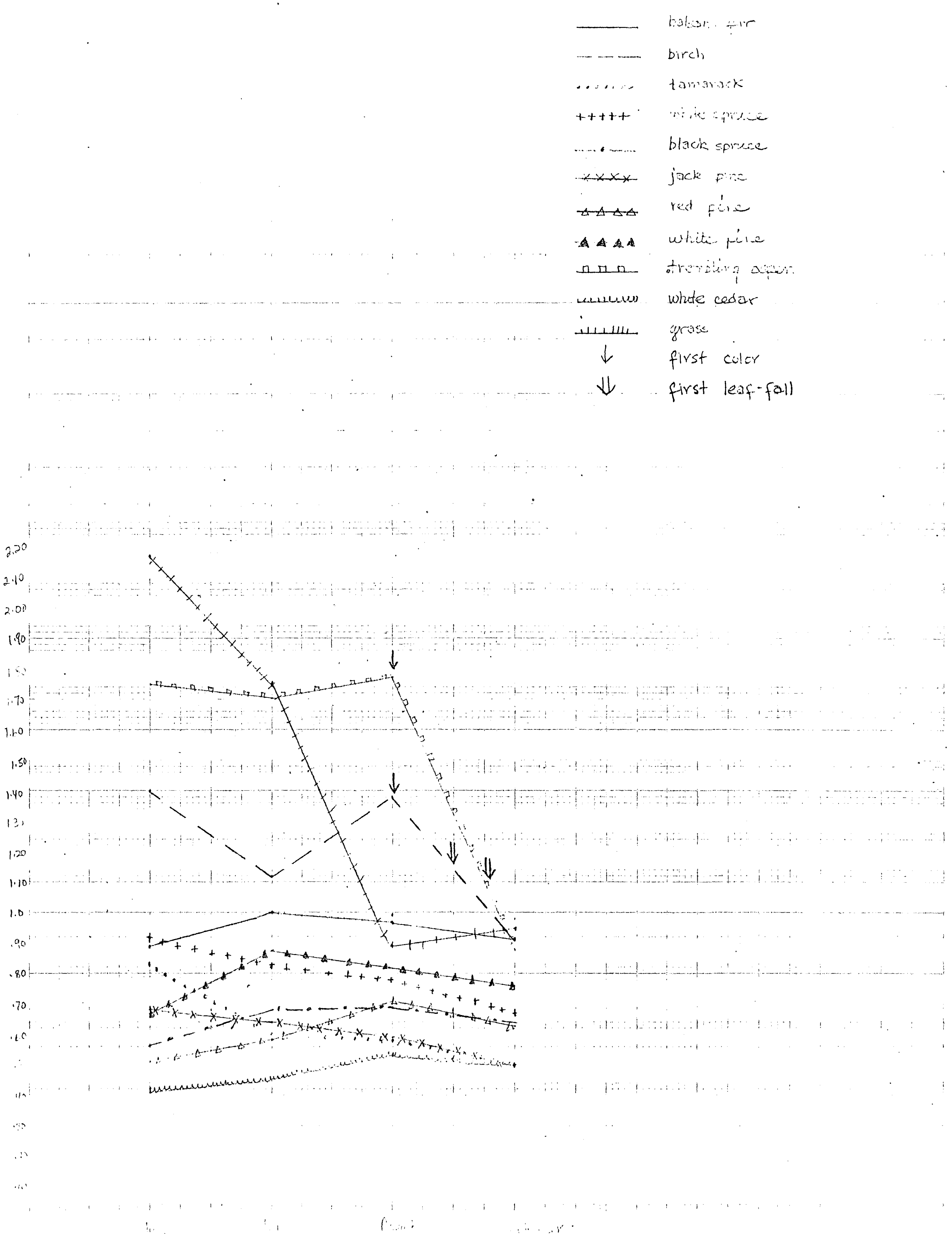
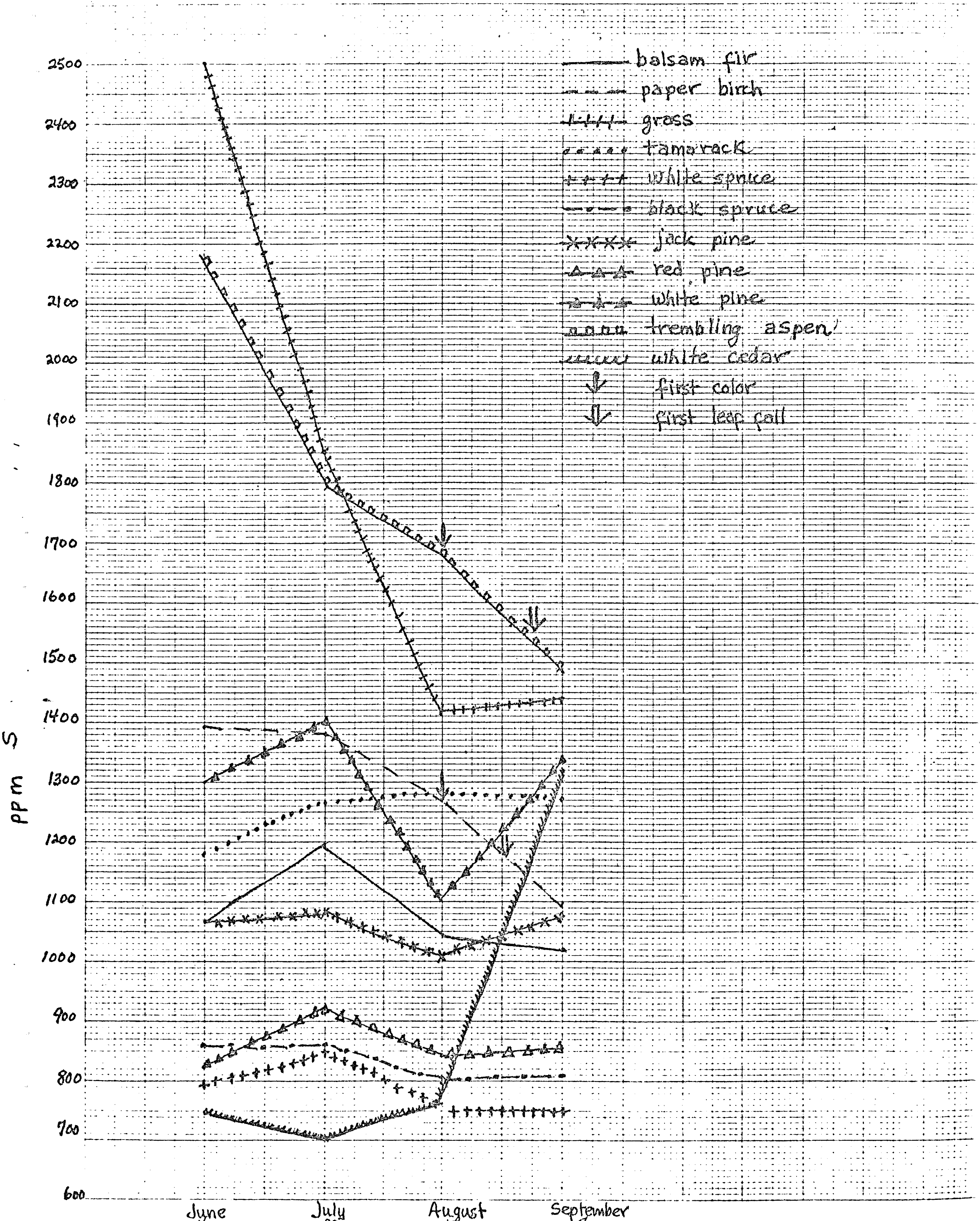
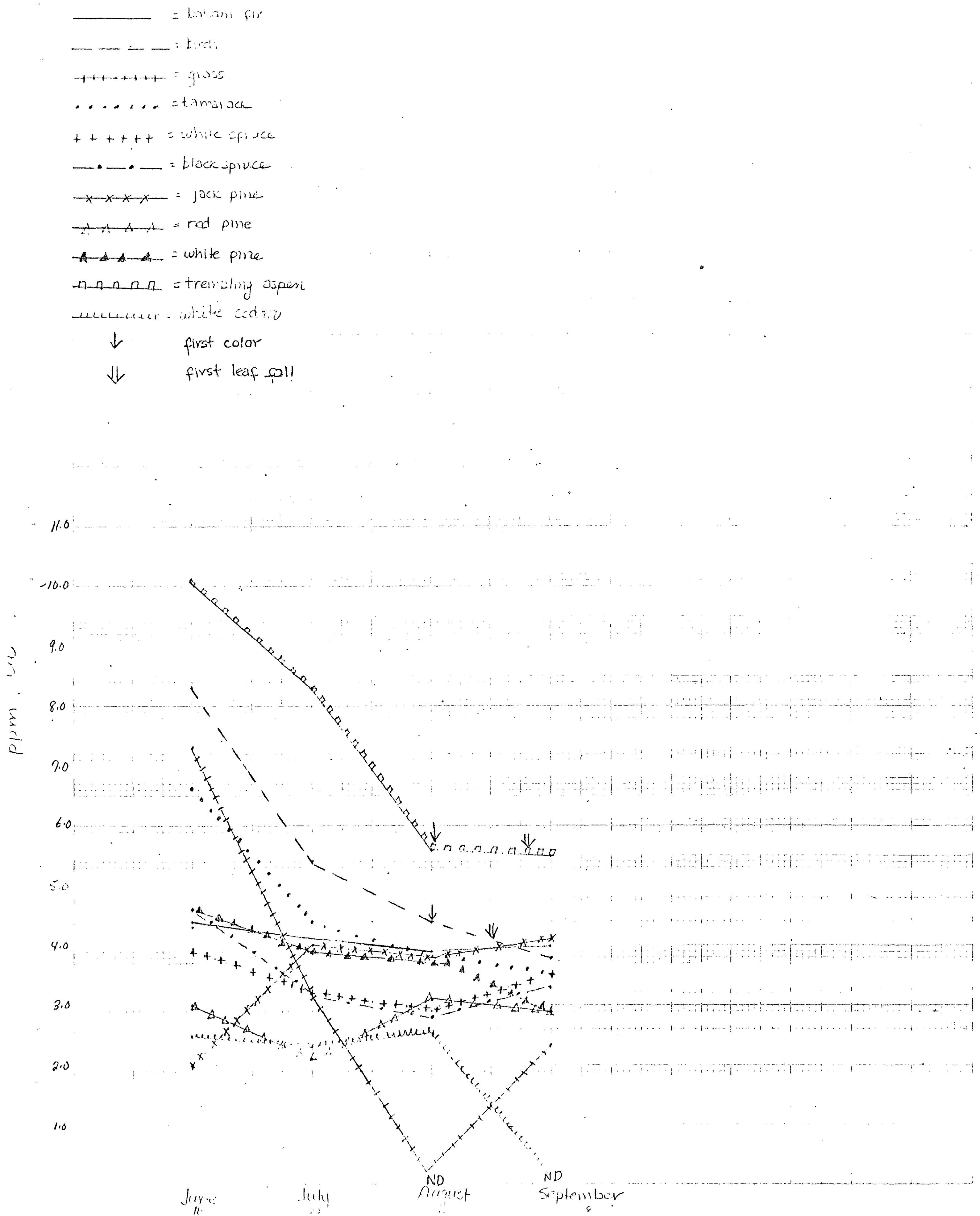


Figure 17 Seasonal Variations in sulphur content of foliage, 1976



ure 12 Seasonal variations in copper content of foliage, 1976



able 19 Seasonal Variations in Zinc Content of Foliage, 1976

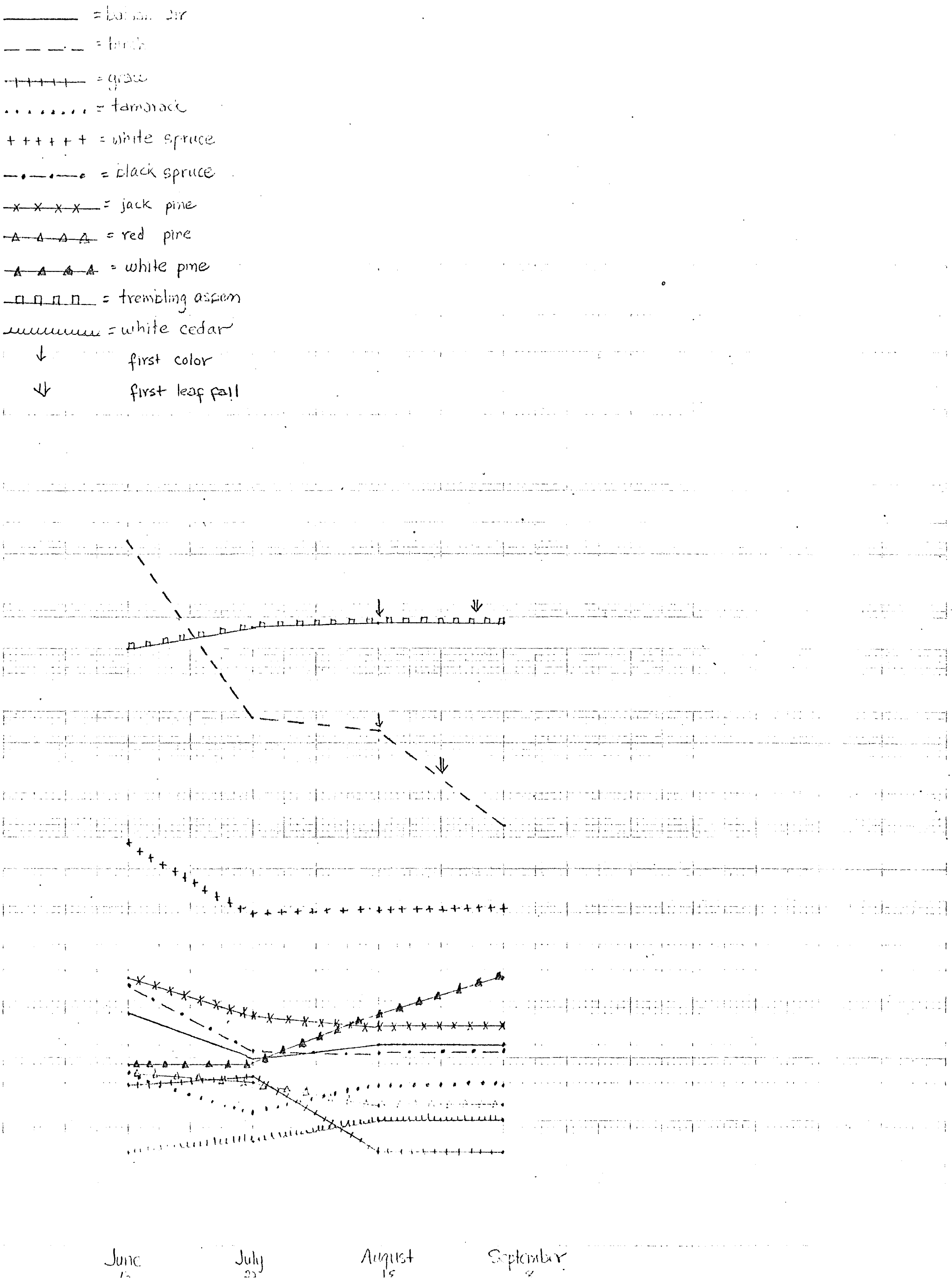


Figure 20 Variations in the nickel content of foliage 1976

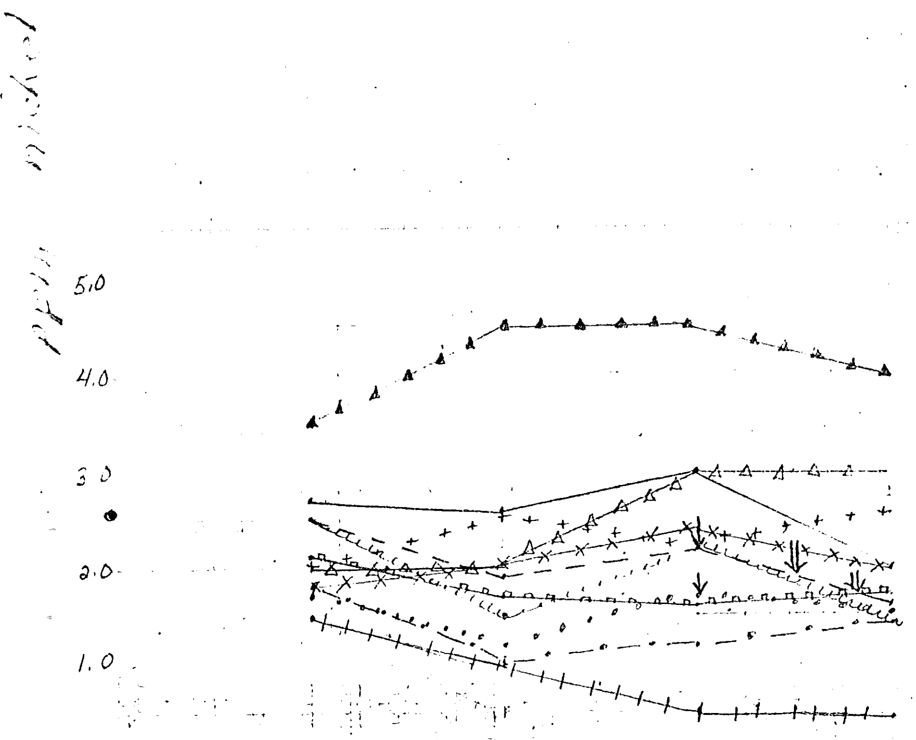


Figure 21 Variations in the flouride content of foliage 1976

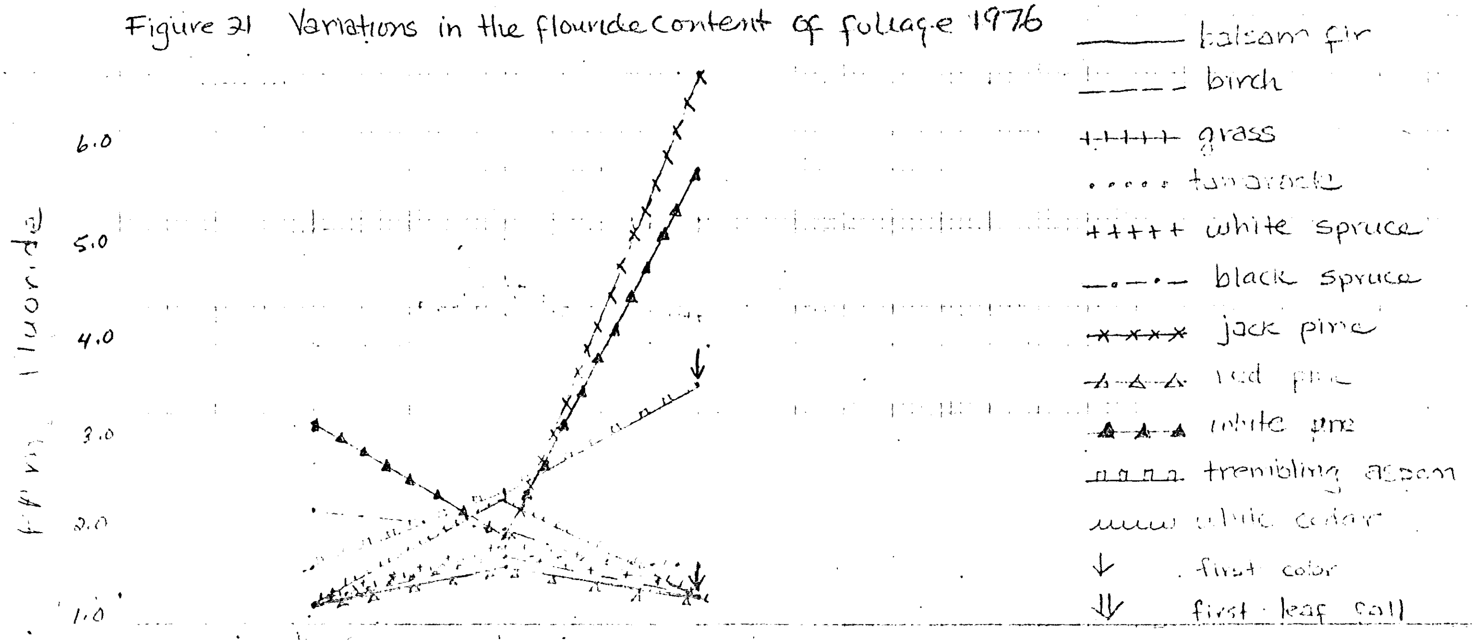
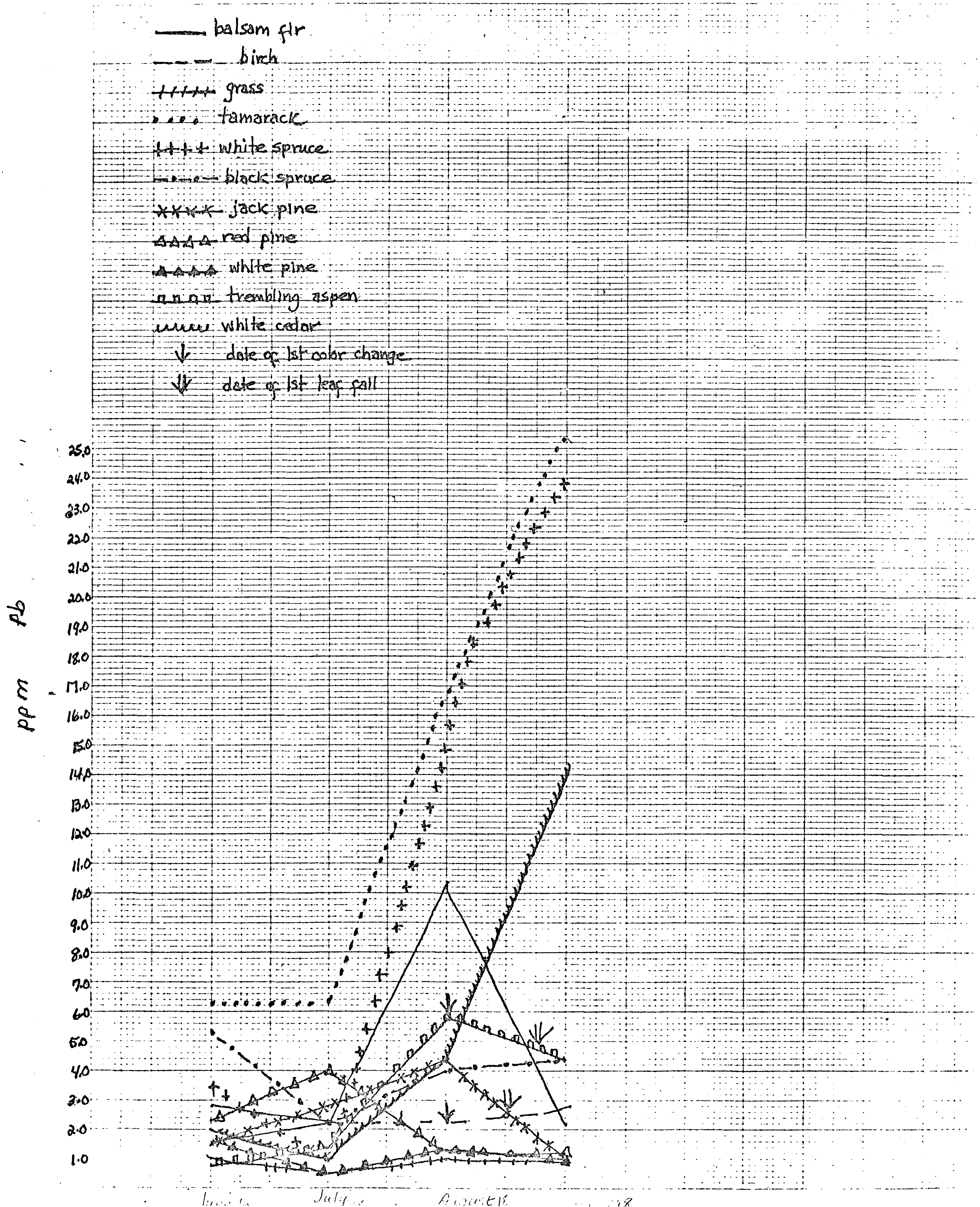
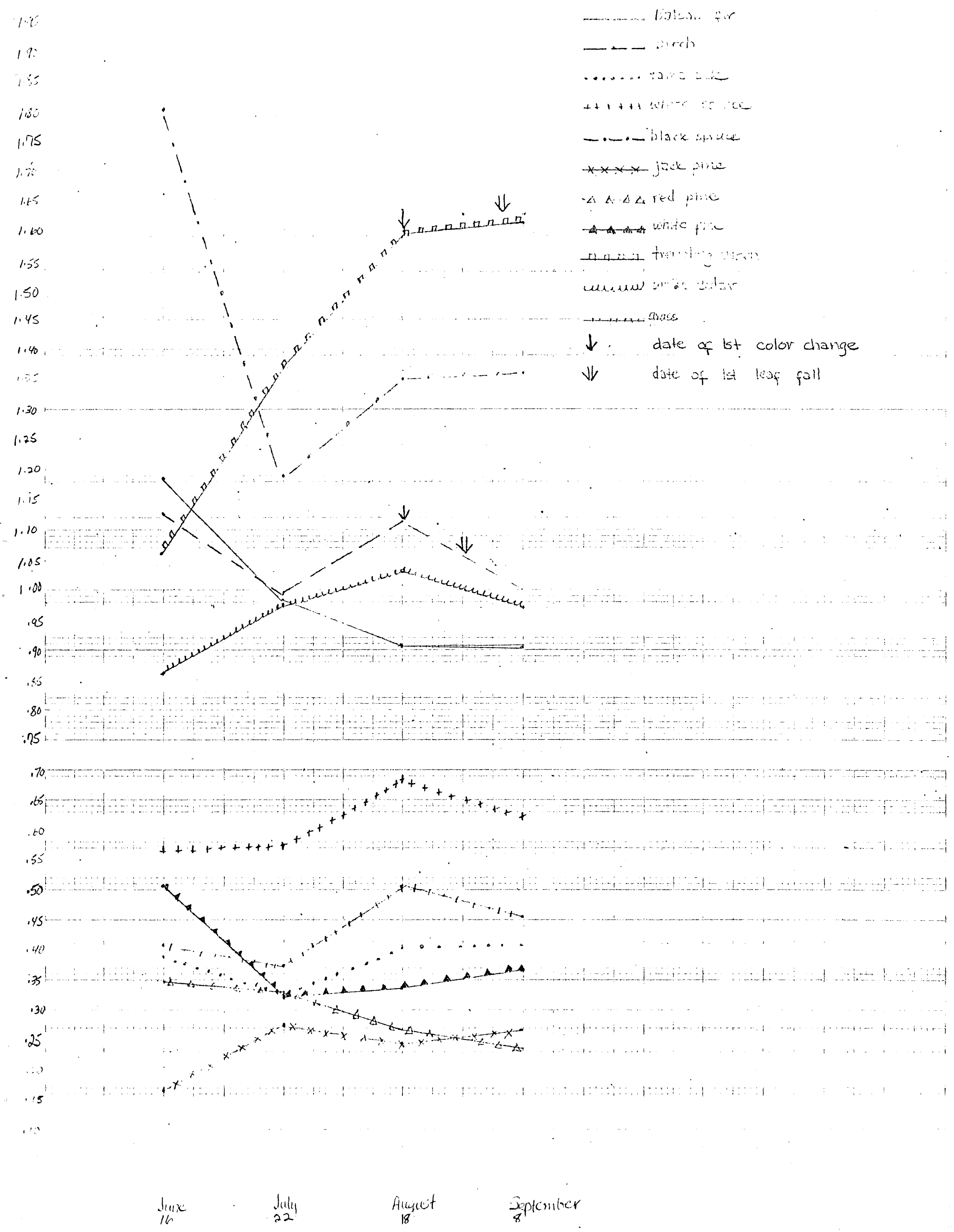
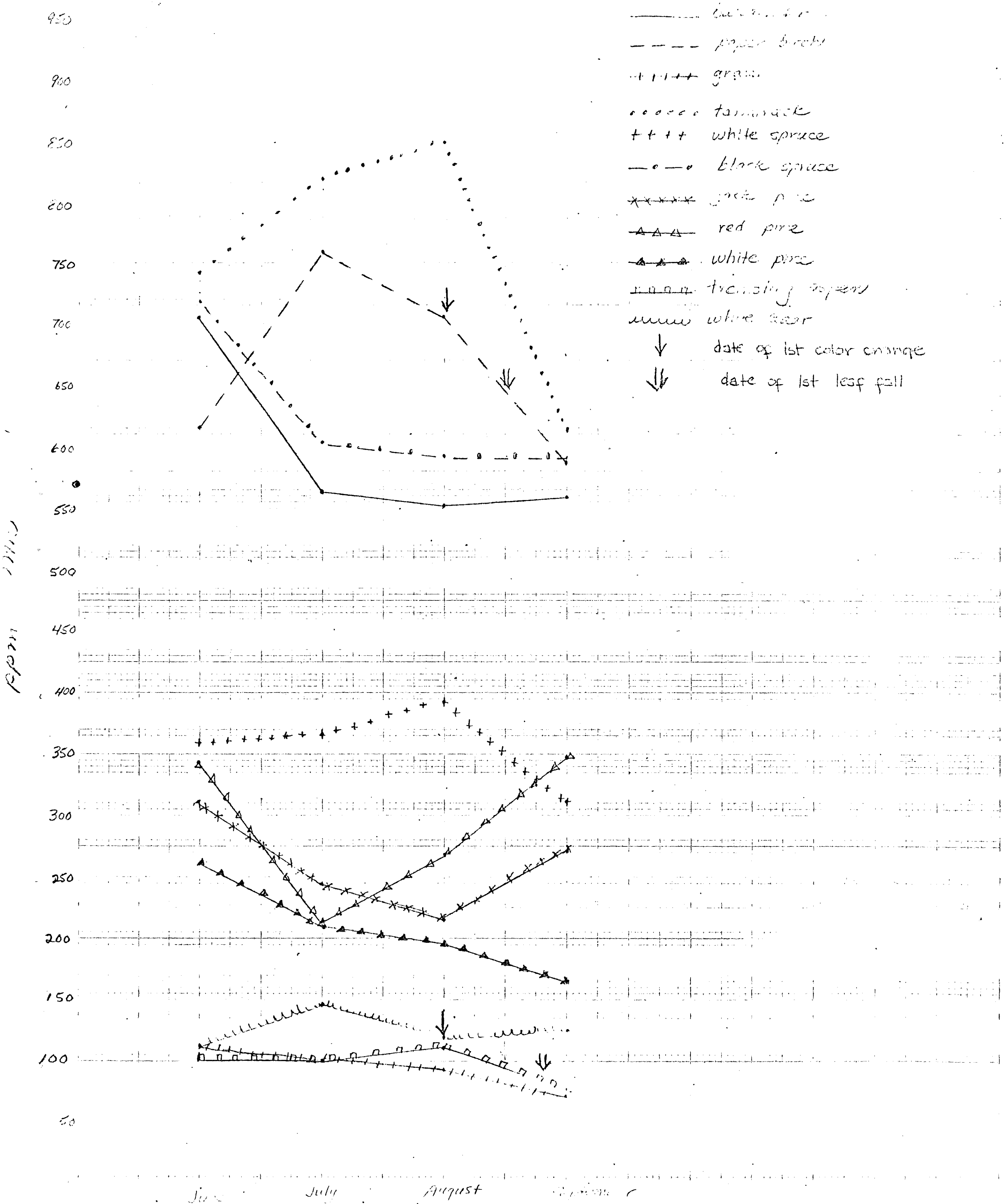


Figure 22 Seasonal variations in lead content of foliage, 1976




1.95
1.90
1.85
1.80
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
.95
.90
.85
.80
.75
.70
.65
.60
.55
.50
.45
.40
.35
.30
.25
.20
.15
.10
balsam fir
birch
tamarack
white spruce
black spruce
jack pine
red pine
white pine
trembling aspen
white cedar
grass
date of 1st color change
date of 1st leaf fall
June 16
July 22
August 18
September 8

me 24 Seasonal variations in manganese content of foliage, 1976



Seasonal variations in phosphorus content of foliage, 1977

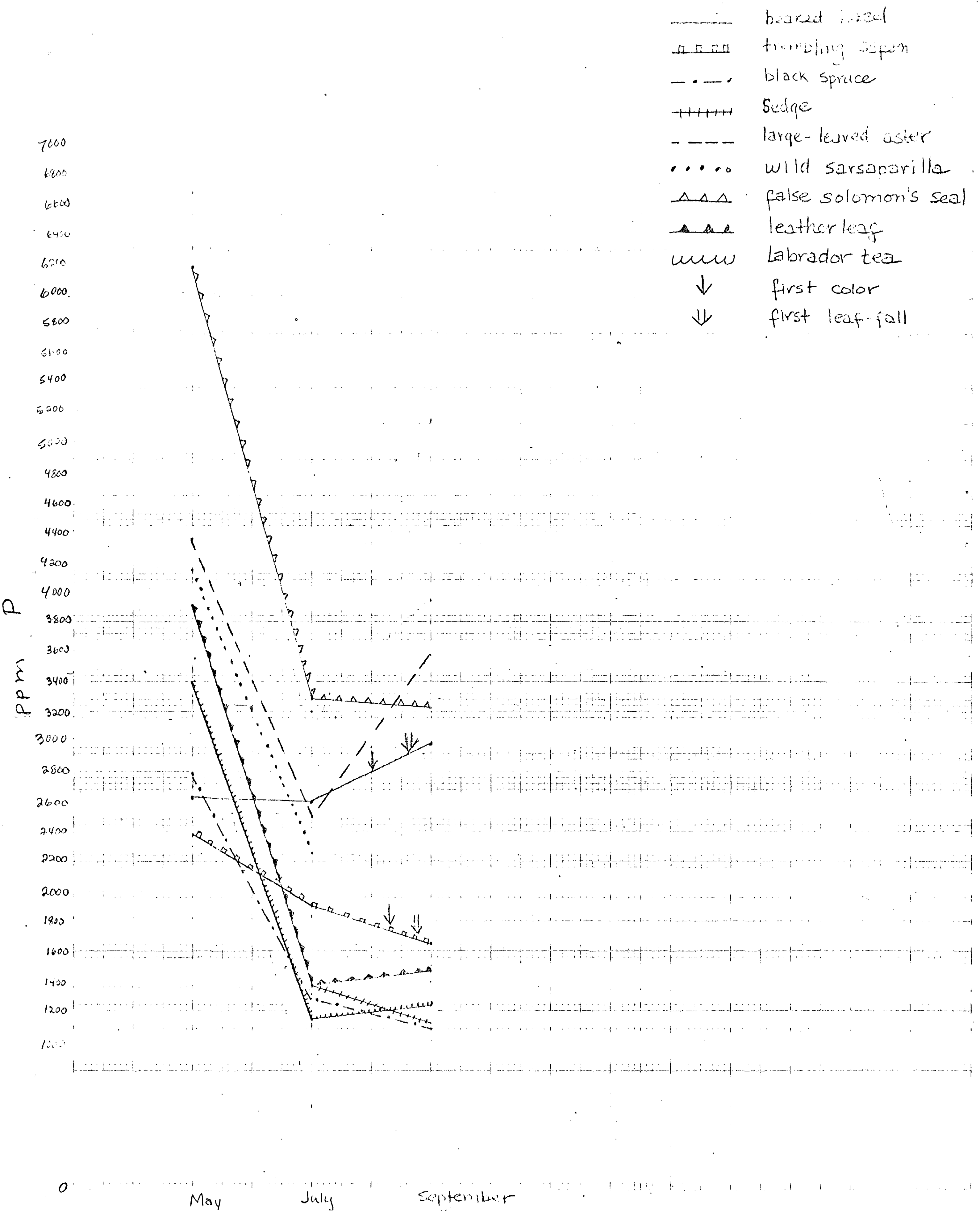


Figure 26 Seasonal variations in iron content of foliage, 1977

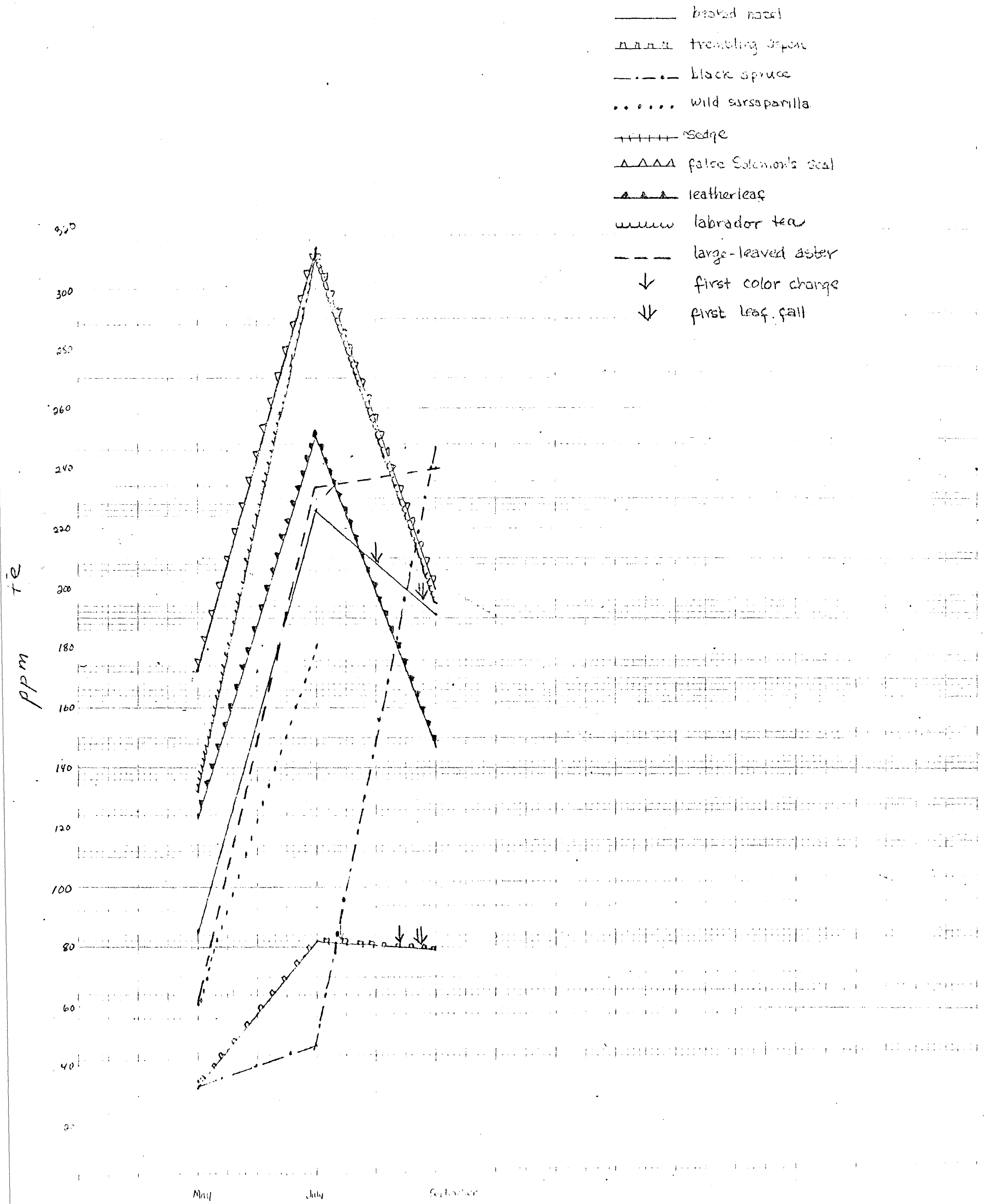


Figure 27

Seasonal variations in potassium content of foliage 1979

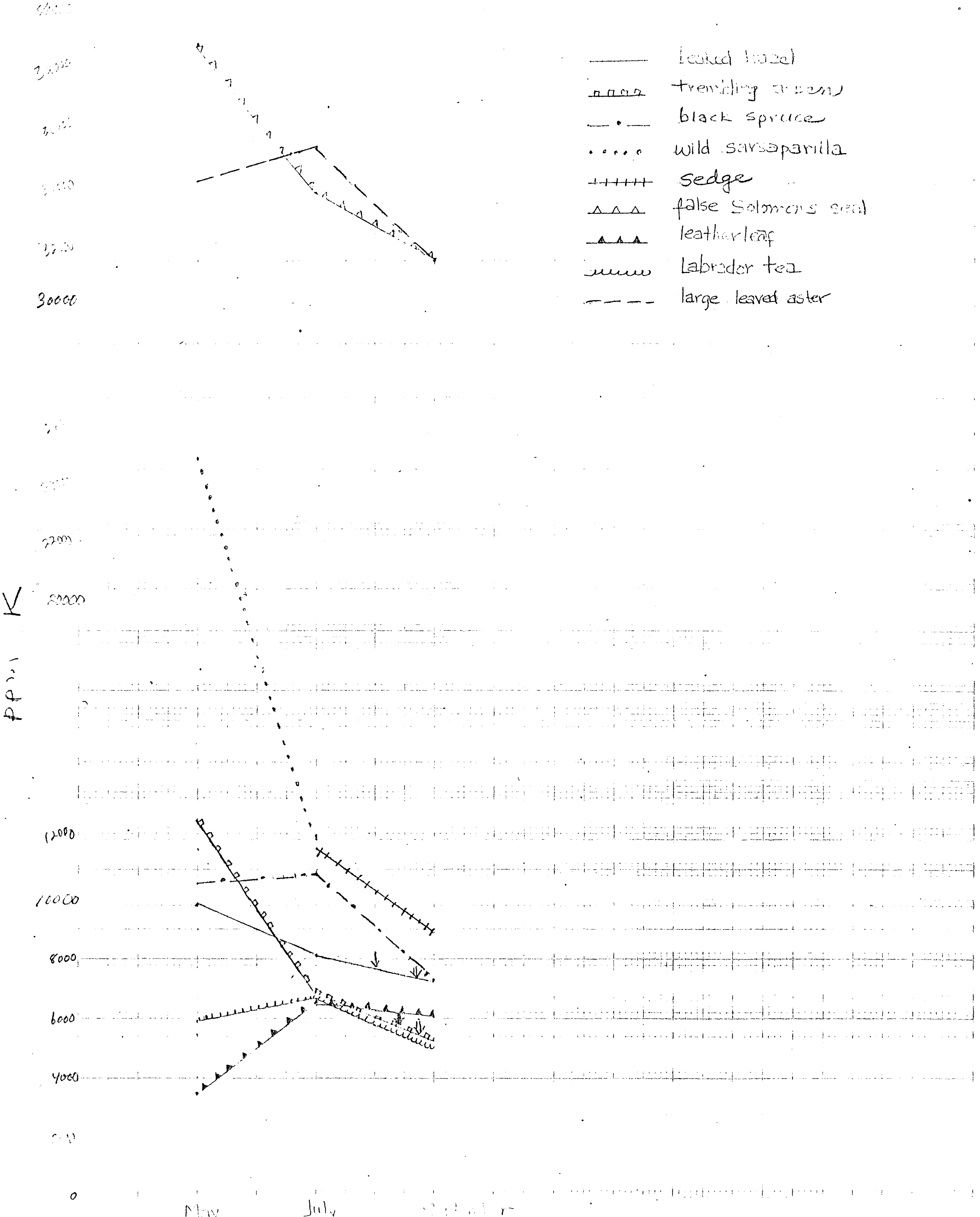


Figure 28

Seasonal variation in Ca content of foliage [illegible]

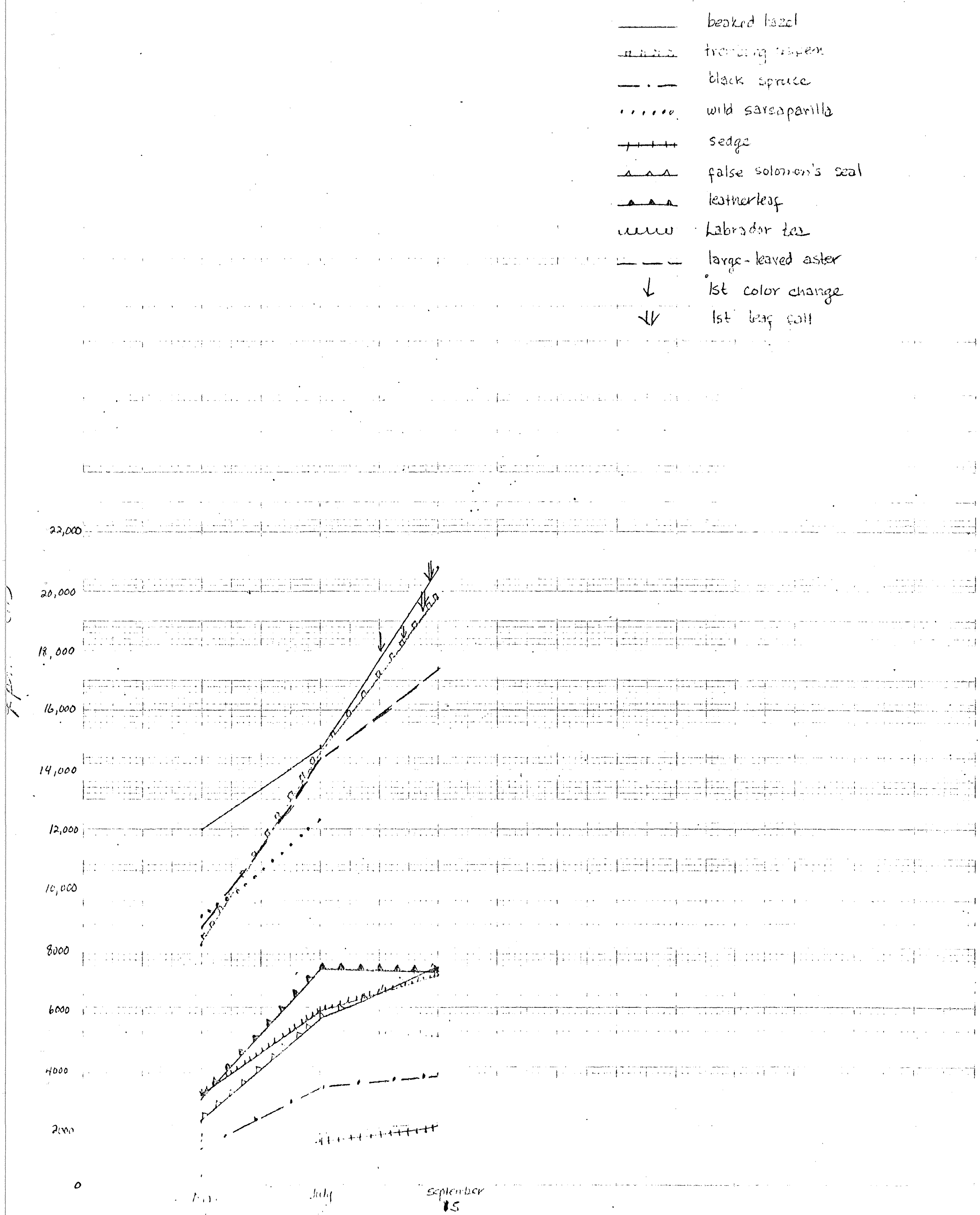


Figure 29

Seasonal variations in Mg content of foliage
1977

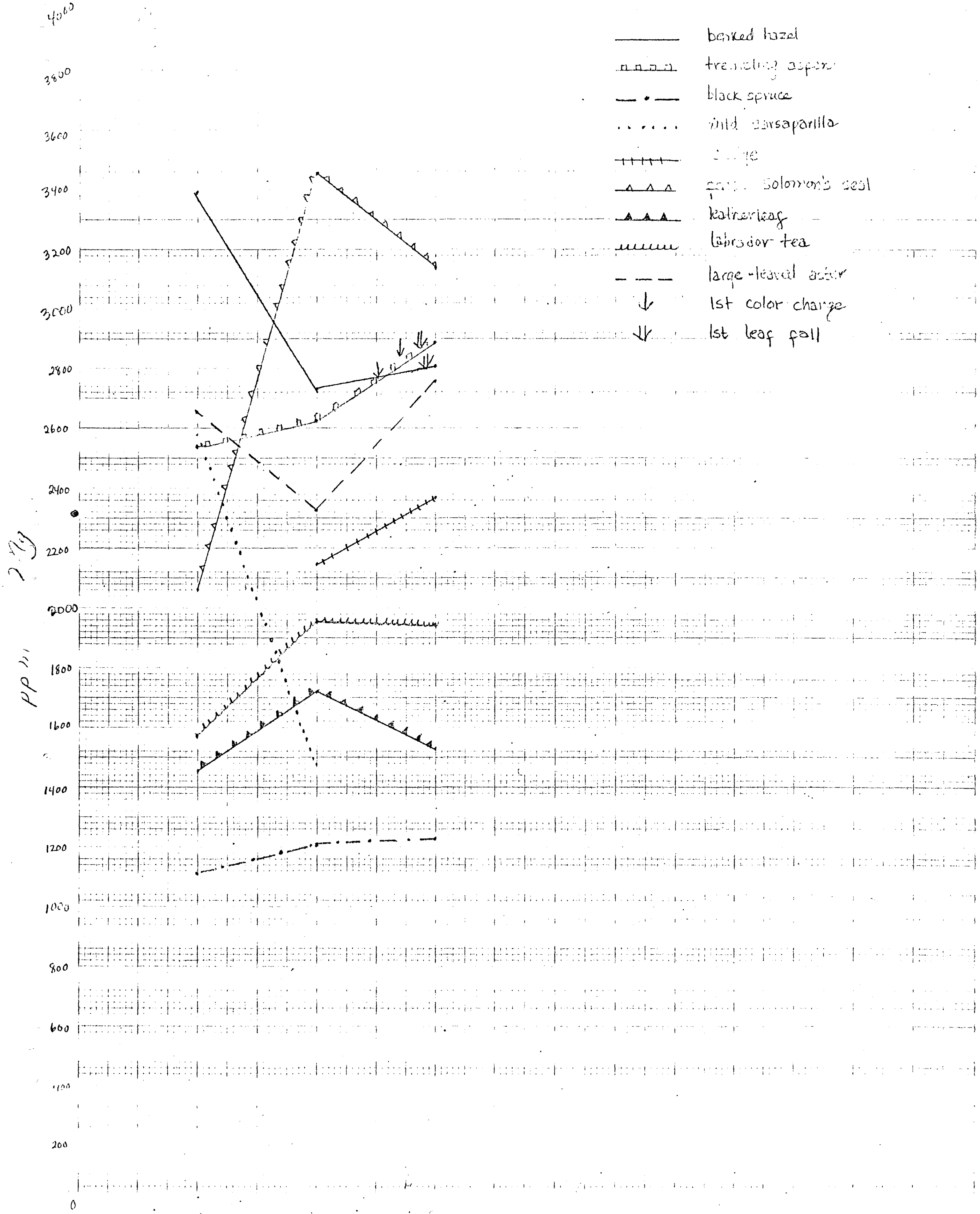


Figure 30 Seasonal variations in manganese, 1977

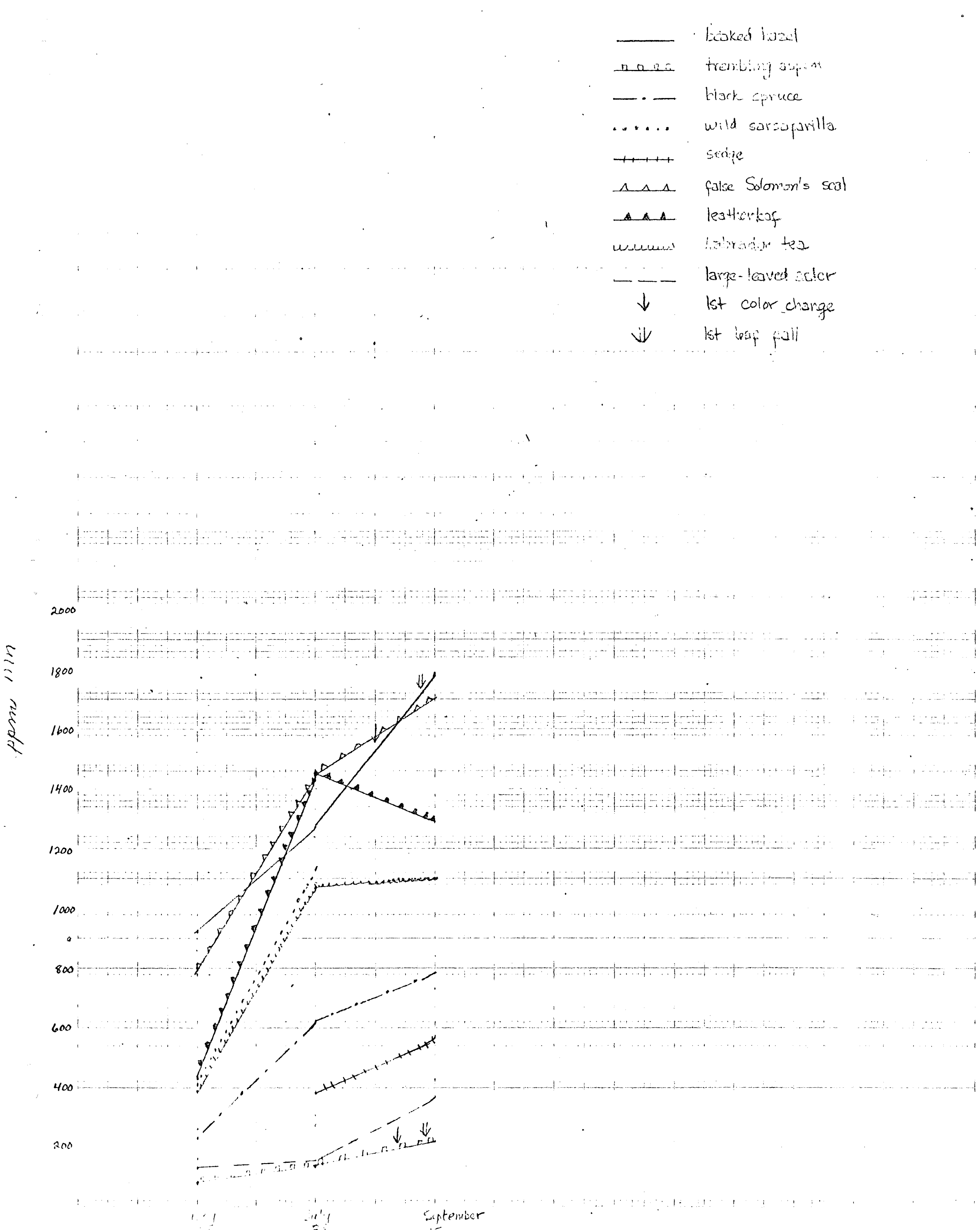


Figure 31

Seasonal variations in copper content of foliage, 1977

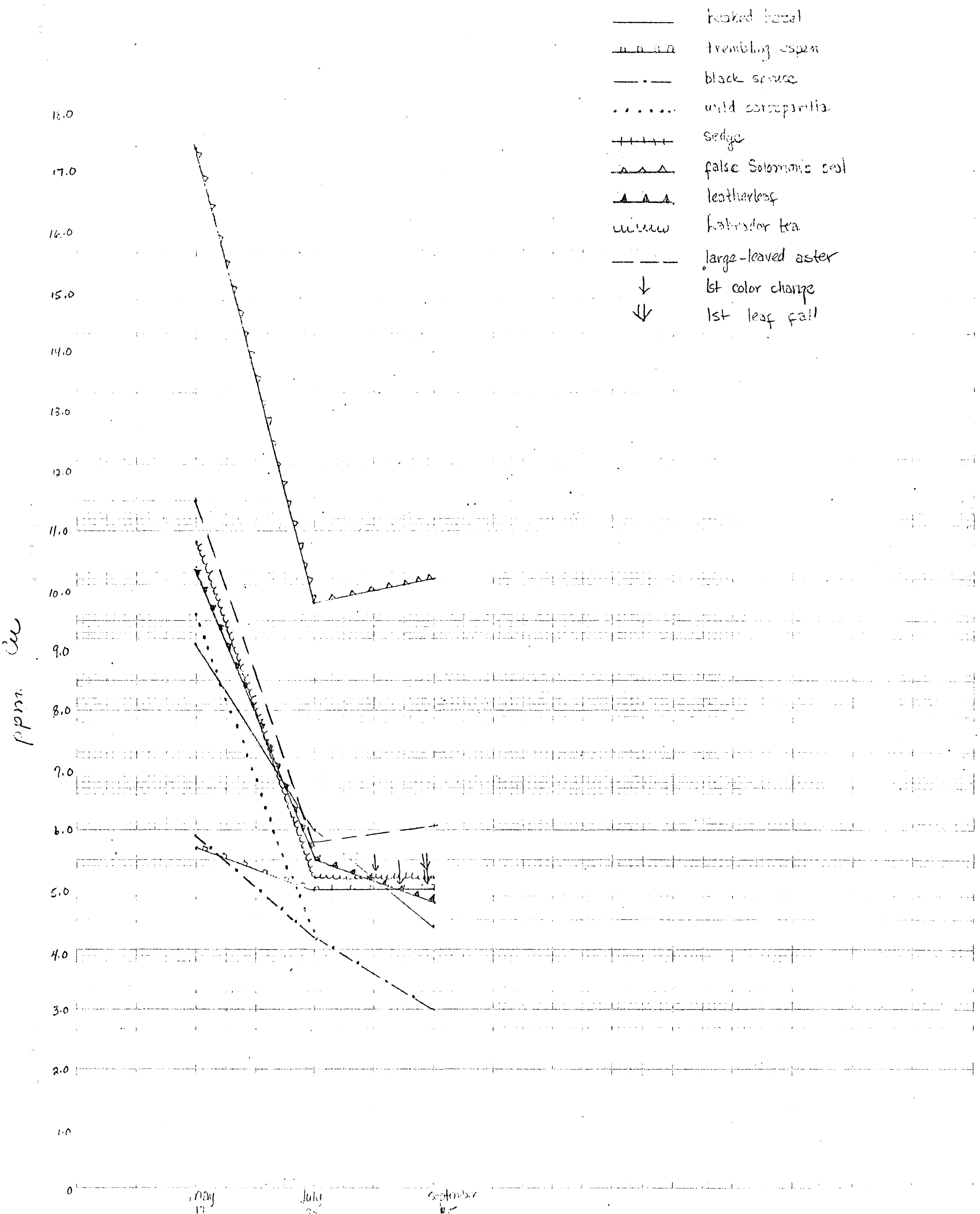


Figure 32 Seasonal variations in zinc content of foliage, 1977

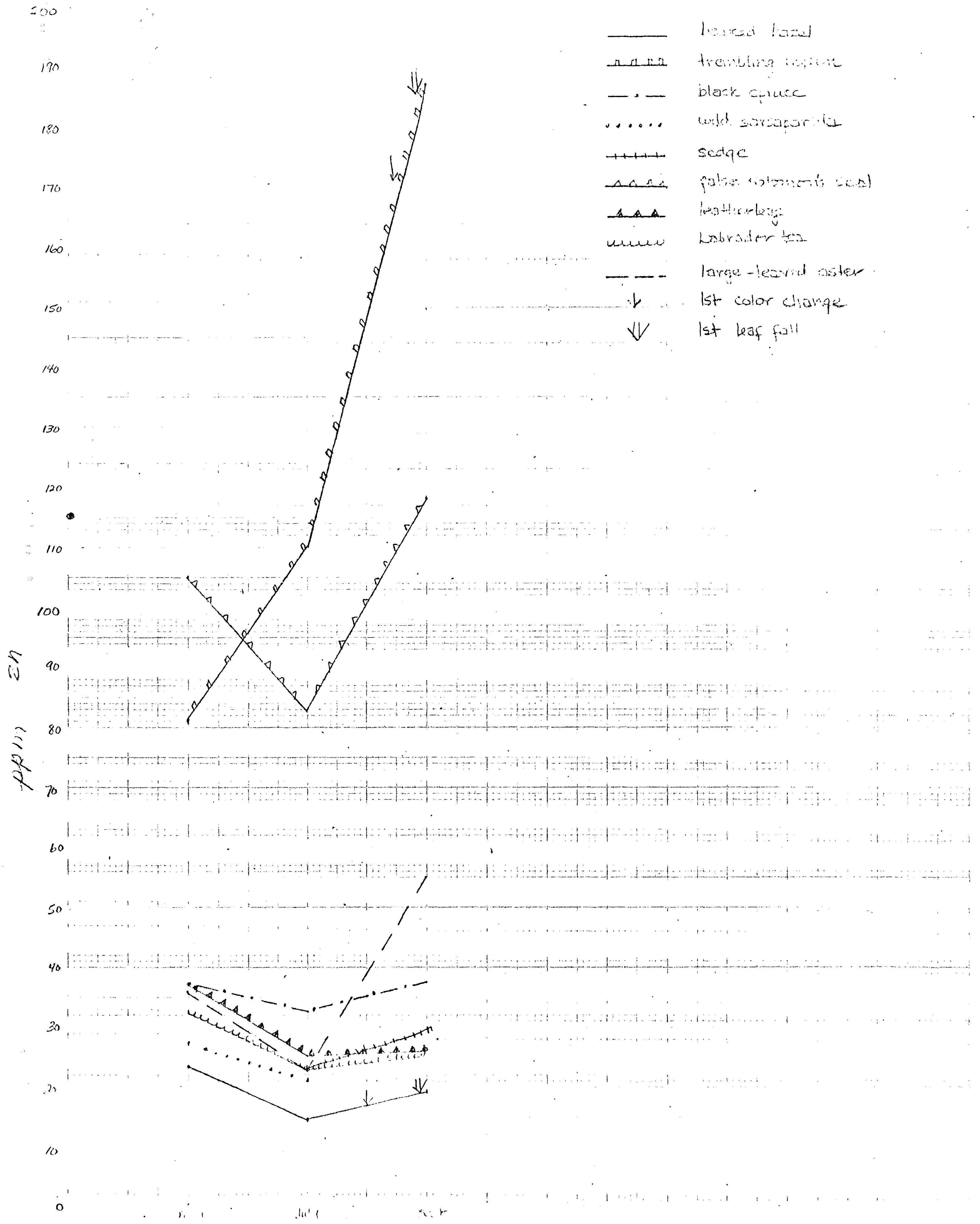


Fig. 33 Seasonal Variations in Aluminum, 1977

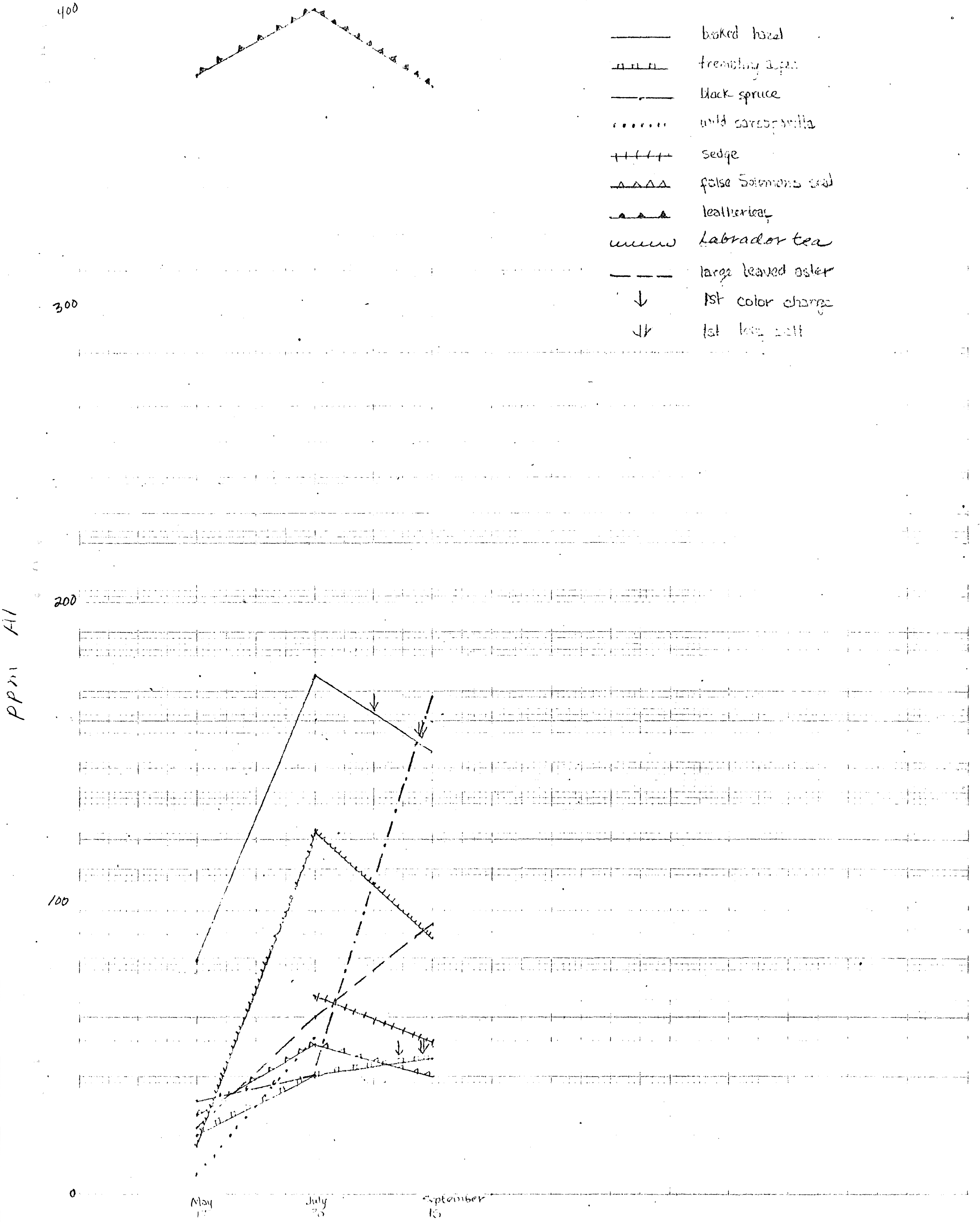


Figure 34 Seasonal variations in chromium, 1977