

# Timothy in Alaska: Characteristics, History, Adaptation, and Management

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## SUMMARY

This report (a) summarizes the characteristics of timothy (*Phleum pratense* L.) as a forage species, (b) reviews briefly the history of its use in the U.S., and the history of timothy evaluations and culture in Alaska, (c) compares winterhardiness of alpine timothy (*P. alpinum* L.) with common timothy, (d) compares physiological and morphological characteristics of timothy cultivars from widely divergent latitudinal origins and relates those characteristics to winter survival, (e) compares planting dates and different seeding–year harvest dates for seeding–year forage production and effects on subsequent winter survival and productivity, and (f) evaluates forage production of established timothy under a broad array of harvest schedules and frequencies, and compares the effects of those harvest treatments on subsequent winter survival and first–cut forage yield the following year.

All experiments were conducted at the University of Alaska Agricultural and Forestry Experiment Station's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska.

- Alpine timothy collections (3 from Alaska, 1 from Iceland) winterkilled 100% during the first winter; in the same test, 22 cultivars of common timothy from northern Europe ranged from 71% to 100% winter survival (Exp. I).

- In addition to inferior winter survival, the comparatively meager production of stems and foliage of alpine timothy, despite adequate added fertilizer nutrients, eliminated that species from consideration as a worthwhile, productive cropland forage grass (Exp. I).

- Strains of North American common timothy, first introduced into Alaska about 1902, generally performed poorly in most areas of the Territory where it was tried. In contrast, cultivars from high latitudes in northernmost Europe, first brought into Alaska in the late 1940's, are markedly better adapted and therefore more winterhardy and productive.

- In general, winter survival was correlated with latitude of cultivar origin; cultivars from northernmost sources exhibited superior winter survival to those from more southern origins (Exps. I, II, III, IV).

- Timothy cultivars from Norway, Iceland, Finland, and Sweden were more winterhardy than those from North America. Furthermore, cultivars from northern Norway and Iceland were more winterhardy than cultivars from southern Norway or from Finland or Sweden (Exps. I, II, III, IV).

- Considering the results of experiments in this report and other experimental tests at this location, the most winterhardy timothy cultivars for use in this area are Engmo, Bodin, and Va–BL–60 from northern Norway, and Korpa and Adda from Iceland (Exps. II, III, IV).

- Northern–adapted cultivars were more dormant in autumn after second forage harvest than mid–temperate–adapted cultivars (Exp. IV).

- The most winterhardy cultivars from North America, when well established, not winter–injured, or only moderately injured, produced total–season forage yields equivalent to Scandinavian cultivars and other extremely winterhardy, non–timothy grasses including Polar bromegrass (predominantly *Bromus inermis* Leyss. X *B. pumpellianus* Scribn.), Garrison creeping foxtail (*Alopecurus arundinaceus* Poir.), Nugget Kentucky bluegrass (*Poa pratensis* L.), and Arctared red fescue (*Festuca rubra* L.) (Exps. III, IV).

- After sustaining sub–lethal winter injury, marginally winterhardy timothy plants displayed a remarkable ability to recover during the growing season and to produce high second–cutting forage yields comparable with harder cultivars (Exps. II, III).

- An insulating snow cover that remained in place during winter provided valuable protection against the stresses of lethally low air temperatures, thaw/refreeze temperature oscillations, or harmful dehydration effects of winter winds. Snow cover in the field greatly enhanced winter survival of marginally winterhardy cultivars (Exp. III).

- Even the most winterhardy timothy strains can sustain severe winter injury or even total winterkill during very stressful winters in this area (Exps. II, III).

- Winterhardy cultivars of rhizomatous grass species survived the more stressful winters better than timothy. The more exposed, superficial position of the overwintering tissues of timothy crowns, relative to the soil surface, renders even the most winterhardy cultivars more susceptible to winter injury than hardy grasses with subterranean, better protected overwintering parts (Exps. II, III, IV).

- The proportion of total–season forage yield produced in the first of two cuttings differed with origin of cultivars in the following ranking: Norway = Iceland = Finland > Sweden > Canada > USA (Exp. IV).

- Engmo, a cultivar of extreme northern origin (69° to 70°N), was more tolerant of freeze stress, stored higher pre–winter levels of food reserves, had higher concentration of dry matter in crown tissues, and survived winters at this location markedly better than Climax, of intermediate latitudinal origin (ca. 45°N), which in turn surpassed Clair in these respects, a cultivar of more southern origin (38° to 39°N) (Exps. V, VI).

- Higher seeding–year forage yields were obtained from Engmo stands planted in mid–May than 1 June; seeding–year yields from both of those planting dates were much higher than from timothy planted in mid–June (Exp. VII).

- Seeding–year harvest in late August harmed mid–June–planted Engmo less than five later harvest dates, but that late–August forage yield was very low (Exp. VII).

- Mid–June–planted Engmo harvested later than early September in the seeding year was predisposed to considerable winter injury (Exp. VII).

- For best seeding–year forage yield, coupled with good winter survival, preliminary results suggest that winterhardy timothy should be planted no later than late May with the seeding–year harvest no later than late August (Exp. VII).

- With established stands, the highest–yielding 3–, 4–, and 5–cut treatments were lower yielding than the highest–yielding 2–cut treatments (Exps. VIII, IX).

- With Engmo timothy harvested twice per year, stands were negatively impacted (as measured by first–cut yields the following year) by progressively later second cuttings from 22 July to 21 September, the latest second–cutting date. This effect was similar with all three different dates of first cutting (10 June, 22 June, 30 June). The 21 September final cutting date also had a slight negative effect on plots harvested three or four times per year.

- With harvest in early June, height of the hidden growing points (shoot apices) in relation to cutting height was critical to rapidity of regrowth. If growing points were below cutting height, growth of tillers continued vigorously. However, if growing points were high enough to be removed in the harvested herbage, growth of those tillers ceased and regrowth developed very slowly from new basal tillers (Exps. VIII, IX).

- Far–northern–adapted timothy strains, with their abundance of basal leaves, are relatively unique among tall–growing forage grasses in being tolerant of more than two cuttings per year (unlike mid–temperature–adapted North American timothies or smooth brome grass). In fact, their subsequent winter survival was enhanced by more than two harvests per year. More than two cuttings per year probably precludes harmful prolonged shading and deterioration of the abundance of basal leaves characteristic of those far–northern timothies (Exps. VIII, IX).

- The modest normal amount of precipitation in this area (15.56 inches annually at the Matanuska Research Farm, 10.17 inches April through September) is marginal to inadequate for realizing the full forage–production potential of timothy. Moreover, very modest precipitation during April, May, and June (normal = 0.63, 0.74, and 1.59 inches, respectively) sometimes severely curtailed the potentially heavy growth during June, especially if precipitation was below normal during the latter portion of the previous growing season (Exps. II, III, IV, VIII, IX). Supplemental sprinkler irrigation can assist in realizing the full forage–production potential of timothy in this area.

## INTRODUCTION

The genus *Phleum*, to which common timothy (*P. pratense* L.) belongs, contains about 10 species worldwide and half of them are annuals. Apparently all are native to Europe and Asia except alpine timothy (*P. alpinum* L., also *P. commutatum* Gand.) which ranges throughout the northern hemisphere in cold and mountainous areas (Hitchcock 1950; Hulten 1968).

### Plant Characteristics

Timothy is a tall, upright–growing, long–lived perennial bunchgrass valued as a forage species in cool–humid agricultural areas of the world. It does not grow well in hot or dry climates; Smith (1972) compared timothy growth under different temperatures and reported it was more productive under a 70°/60°F day/night combination than under warmer (90°/80°, 80°/70°) or colder (60°/50°) conditions. Moreover, storage of food reserves in timothy stem bases was greater when grown with cool (65° day/50° night) than with warm (85° day/70° night) temperatures (Smith and Jewiss 1966). Those temperatures cited as ideal concur well with general growing–season temperatures in Alaska.

Timothy grows best on soils well supplied with moisture; its relatively shallow root system is less extensive than more drought–tolerant species (Lambda *et al.* 1949). This characteristic of timothy was recognized early, for Piper and Bort (1915) quoted from a letter of 14 July 1793 from George Washington to overseers of his lands: “The lowest and wettest part thereof is to be sown with timothy seed alone. All other parts of it are to be sown with timothy and clover seeds mixed.”

Timothy is utilized for hay, pasture, and silage (McElroy and Kunelius 1995; Hanson 1972). It long served as the principal hay for horses and mules. Timothy is most commonly grown in mixture with red clover, but also in association with other grasses and legumes (McElroy and Kunelius 1995; Smith *et al.* 1986).

Timothy is quick to establish (Smith *et al.* 1986). This characteristic was noted long ago; Piper and Bort (1915) quote from a 1763 letter, “As to Timothy–grass, it grows prodigiously quick.” Despite its very small seeds, timothy seedlings develop very rapidly once the first few leaves have been produced (Fig. 1).

Although far–northern–adapted timothy cultivars produce few elongated culms during the seedling year (Klebesadel 1970, 1992a; also Fig. 1), virtually all elongated culms produce seed heads in the spring growth of subsequent years. Unlike brome grass that must be planted as early as possible to promote maximum heading for seed production in the second year, Engmo timothy can



Figure 1. Individual seedling plants of *Engmo timothy* showing amount of growth produced from the date of seeding (indicated under each plant) until photographed on 12 October. Note meager amount of heading during the seedling year and heavy production of basal leaves. Black lines are eight inches apart.

be planted as late as late June to early July and produce a seed yield (in the second year of growth) as large as from earlier-planted rows (Klebesadel 1970).

Seed heads of timothy are narrow and spike-like (Fig. 2). Most seed heads are from two to four inches long, but length can vary considerably, depending on whether they are borne on primary or secondary tillers, and the time of origin of tillers (Langer 1956). Soil fertility and moisture supply also can influence seed-head length. Under poor growing conditions they can be so short as to appear almost ball-like, but under very favorable



Figure 2. *Engmo timothy* seed heads photographed on 4 July showing how length of heads may differ. The two at left are pre-anthesis; right pair is near full anthesis (flowering stage) with pollen-producing anthers fully extended.

conditions they may exceed five inches in length.

Timothy is sometimes confused with meadow foxtail (*Alopecurus pratensis* L.), another cool-season grass grown to a limited extent in Alaska. The confusion arises from the general similarity of the shape and appearance of the seed heads. Close inspection can easily differentiate the two on the basis of the more tapered ends of the heads of meadow foxtail and by the shape of individual spikelets within the seed heads (Fig. 3).

Timothy is somewhat unique among cultivated grasses in having the lower one, two, or three internodes of the stem bases enlarged into small bulb-like structures called haplocorms or corms (McElroy and Kunelius 1995; Peters 1958; Sheard 1968; Smith *et al.* 1986; Waters 1915). Those corms serve as the principal storage site for food reserves (Knoblauch *et al.* 1955; Reynolds and Smith 1962; Sheard 1968). The dominant available carbohydrate stored in stem bases of timothy is fructosan with very small amounts of sucrose, in contrast to Alaska's other dominant forage grass, smooth brome grass, which stores primarily sucrose with very little fructosan (Okajima and Smith 1964).

The nodes adjacent to the corm, primarily at its base, are the sites of origin of new tillers or shoots (Fig. 4) that grow to become elongated culms or stems. Although the individual corms live only as biennials or winter annuals that disintegrate in their second year, the continual regeneration of new tillers from living corms confers perenniality on the total plant (Brown *et al.* 1968;

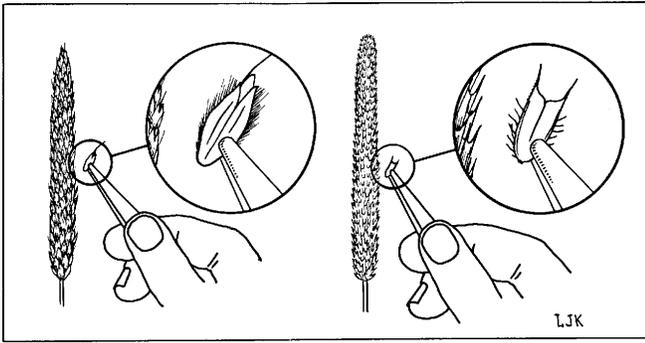


Figure 3. Seed-head characteristics that assist in differentiating timothy and meadow foxtail. Seed head of meadow foxtail (on left) is more tapered than timothy at both ends; an individual spikelet removed from seed head (magnified in circle) is widest at its midpoint, narrowing toward tip. Timothy seed head (on right) appears somewhat more bristly; an individual spikelet is widest near distal end and terminates in two near-parallel, short, scabrous awns.

Evans *et al.* 1939; Langer 1956; Peters 1958; Sheard 1968; Waters 1915).

### Plant Development and Forage Quality

The good palatability and nutritional value of timothy has been known since its early cultivation; a New England letter of 1790 comments: Timothy-grass, a coarse grass, but very agreeable to all sorts of cattle.” Moreover, herbage of this species is highly digestible and compares favorably with many other grasses (Collins and Casler 1990; Klebesadel 1994b; Kunelius *et al.* 1974; Mitchell 1982, 1986, 1987).

As with other grasses, however, digestibility of the initial growth of the season declines with progressive stages of plant development and this becomes a factor to consider in first-cut harvest timing to obtain forage with a desired combination of yield and quality (Grant and Burgess 1982; Kivimae 1966; Klebesadel 1994b; Kunelius *et al.* 1976; Waldie *et al.* 1983). Brown *et al.* (1968)

summarized numerous published reports on timothy forage quality factors and digestibility, as influenced principally by plant growth stages and nitrogen fertilization.

In general, crude protein concentration, dry-matter digestibility, and leaf-to-stem ratio decrease, and lignin increases, with advance in plant development and maturation in the initial growth of the season. Landstrom (1990) in northern Sweden reported that maximum crude protein in herbage occurred about 20 days after initiation of spring growth, and maximum digestibility was reached about five days later. The very leafy regrowth of far-northern-adapted timothy was found to surpass regrowth of several other grass species in digestibility (Klebesadel 1994b).

### Responses of Timothy to Fertilizers

Numerous studies have been conducted elsewhere on the effects of fertilizers on timothy forage productivity, nutritive value, physiological behavior, and stand persistence (Bonin and Tomlin 1968; Brown *et al.* 1968; Jung *et al.* 1974; Knoblauch *et al.* 1955; Kunelius *et al.* 1976; Lindberg 1988; Lindgren and Lindberg 1988; Sheard 1968; Smith and Jewiss 1966; Thorvaldsson and Andersson 1986). Similarly, timothy in Alaska has been



Figure 4. Engmo timothy stem bases with dead sheath coverings peeled away to reveal enlarged bulb-like internodes called corms or haplocorms. Also visible are roots and several new tillers arising mostly from corm bases (one on left growing from node at top of corm). Those new tillers remain in a state of arrested growth over winter, then elongate to become primary herbage growth the following spring. Photograph 14 November of seedling plants from 13 May planting. Ruler length is 10 centimeters (4 inches).

found to respond favorably to, and have critical requirements for, certain added nutrients in different areas of the state (Laughlin 1965; Laughlin *et al.* 1976, 1977, 1981).

## Timothy History in North America

Early American colonists referred to timothy as “Herd’s grass” after John Herd, who reportedly found it growing wild along the Piscataqua River near Portsmouth, New Hampshire about 1711 (Piper and Bort 1915). An early promoter of its use, Timothy Hanson, took seed to New York, Maryland, Virginia, and North Carolina; this led to the grass being called “timothy” (Edwards 1948; Piper and Bort 1915).

Benjamin Franklin, apparently confused by the two names, ordered some “herd–grass seed” from a Jared Eliot. Franklin’s letter of 16 July 1747 to Eliot contains: “You made some mistake when you intended to favor me with some of the new valuable grass seed (I think you called it herd–seed), for what you gave me is grown up and proves mere timothy” (Piper and Bort 1915).

The cultivation of timothy spread throughout New England during the 1700’s. Piper and Bort (1915) quote from an 1807 report: “Timothy grass —is more extensively cultivated than any other grass in the United States.”

Evans (1937) stated that breeding for improved cultivars of timothy was first undertaken in the U.S. Although no improved cultivars had been produced at the start of this century, breeding work had begun at several midwest and northeastern U.S. locations at about that time and several named cultivars appeared in the first decades of this century (Evans 1937; Hanson 1972).

Piper and Bort observed in 1915: “Timothy is by far the most important hay grass cultivated in America and for a century at least has occupied this economic position.” As late as the middle of this century, Hitchcock (1950) referred to it as “our most important hay grass.” The popularity of timothy and its acreage in the U.S. have declined, however, during recent decades (McElroy and Kunelius 1995; Smith *et al.* 1986). Several factors that have influenced that decline include the decrease in numbers of horses and mules, increased availability of improved cultivars of smooth brome grass and orchard grass, comparatively poor regrowth of timothy under warm, dry conditions, and the increased popularity and use of alfalfa and corn silage.

Several reports consider common timothy to be of European origin (Edwards 1948; Hanson 1972; McElroy and Kunelius 1995; Smith *et al.* 1986). Some early writings mention the grass growing naturally in England where it was called “cat’s–tail grass” and “meadow cat’s–tail” (Piper and Bort 1915). Piper and Bort (1915) cite

conflicting opinions by two of America’s eminent early agrostologists, George Vasey claiming in 1884 that timothy is “undoubtedly indigenous” in America, and M.L. Fernald convinced that it was introduced.

Early records indicate that timothy was first cultivated in America, and seed was taken to England prior to 1746 and again in the 1760’s. Despite considerable confusion, most who have studied the issue tend to agree that timothy was introduced into America from Europe (Piper and Bort 1915). Edwards (1948) theorizes that the species probably became established in North America with seed carried from Europe by early settlers in litter, hay, manure, or ballast cleaned from ships.

Walton (1983) has set forth a different viewpoint on the origin of common timothy, at odds with the contention of the above reports that this species came to North America from Europe. He stated that common timothy can be synthesized by crossing the diploid *P. bertolonii* D.C. ( $2n=14$ ) with tetraploid *P. commutatum* Gand. (= *P. alpinum*) ( $2n=28$ ). The progeny of that cross, a triploid hybrid, is sterile but, by chromosome doubling, the hexaploid common timothy ( $2n=42$ ) can be obtained. Chromosomal relationships of these species have been reported by Wilton and Klebesadel (1973).

Walton notes that *P. bertolonii* was introduced into this continent by early settlers from Europe; thereafter that species spread rapidly in America and came into contact with the native alpine timothy. Walton further states: “It is believed that crossing of the two species and subsequent chromosome doubling occurred in the New England states during the seventeenth century,” after which timothy was taken to England and later spread rapidly in Europe.

## Timothy History in Alaska

Piper (1905) commented that timothy grown in early trials at Sitka was “not promising.” He further stated, “Timothy is more or less abundantly introduced at various places on the (southern Alaska) coast, but does not as a rule thrive very well, being often inferior in size to the native mountain timothy.”

In a report on agricultural resources on the Kenai Peninsula, Bennett (1918) stated, “Mountain timothy, a short barleylike grass, forms an important part of the pasturage of mountain sheep and goats.” In the same report, he wrote, “Timothy has not done well—in the vicinity of Knik,” but noted that he had seen timothy cut for hay in 1916 near Seward.

Irwin (1945) summarized 47 years (1898–1945) of evaluation trials with grasses and legumes at seven widely dispersed experiment stations in Alaska. Timothy grown at

the Sitka station in maritime, southeastern Alaska from 1902 to 1905 was “not well adapted to this section of Alaska.” Grown from 1902 to 1908 at Copper Center in the Copper River Valley, it was “too dry for timothy, not dependable.” In volcanic ash on Kodiak Island it grew only 3 to 4 inches tall in 1913. At Rampart, the northernmost station that was located on the Yukon River in interior Alaska, timothy grown from 1906 to 1910 was “— short, spindling, winter-killed.” Grown in various years from 1909 to 1939 at the Fairbanks station in the central Tanana River Valley, timothy performance was described as “— good first year, poor later, too short for hay.”

Planted at the Matanuska Station in 1917, timothy “— survived winter but growth disappointing.” Other plantings from 1919 to 1942 were summarized: “kills during dry winters, second year yields good, responds to nitrogen.” Alberts (1933) ranked slender wheatgrass and smooth brome grass as the best forage grasses tried at the Matanuska station; he further commented, “Timothy overwinters well, but does not make a satisfactory hay crop.”

Best results with timothy were reported for the Kenai station where winters are somewhat milder and moisture more abundant than at interior stations. Descriptions of plantings there from 1902 to 1906 included “10 to 60 inches tall, reliable, one of best grasses for this district.”

In a comprehensive summary assessment of agricultural development and forage crop performance in Alaska at mid-century, Aamodt and Savage (1949) stated concerning timothy: “Trials in most sections of Alaska show that it is not well-adapted to the soil and climatic conditions, except in the coastal districts and central interior. For 1 or 2 years it makes fairly heavy growth, but after the second year crops are light.— Leaf growth of timothy is less heavy than that of brome grass, tall oatgrass, or meadow fescue.”

## **A New Source of Timothy for Alaska: Latitude Relationships**

All of the above plantings, showing predominantly disappointing results with timothy throughout Alaska, undoubtedly were grown with seed adapted to, and obtained from, mid-temperate areas of the U.S. A pivotal occurrence in 1948–49, however, changed the outlook for timothy in Alaska and opened the door on recognition of the importance of latitudinal adaptation for successful culture of many other perennial forages in this northern territory and state. Dr. H.J. Hodgson, an agronomist at this station, established contact with agronomist Dr. Karl Flovik of Tromsø, Norway, a coastal city north of the Arctic Circle. Among other crop strains obtained

from northern Norway for evaluation in Alaska was a timothy cultivar named Engmo. In correspondence describing the origin of Engmo, Flovik stated in a 1958 letter to then Alaska agronomist Dr. A.C. Wilton:

“Engmo timothy is a local strain from the county of Troms. In a mountain valley between 69 and 70 degrees north latitude where the elevation is about 400 metres above the sea level, one of the small farms has the name Engmo. Some time before 1920 the owner of this farm had sown a field with timothy using commercial seed of unknown origin. In 1930 there still were a few timothy plants left in this field. As these plants had to be very winter-hardy, seed of some of them was collected and sown at the State Agricultural Experiment Station Holt at Tromsø. It soon became clear that we through natural selection had got a very winter-hardy and at the same time high-yielding strain of timothy. The strain was given the name Engmo from the farm mentioned above and steps were taken for commercial seed production.

“Engmo timothy is leafy, winter-hardy and high-yielding and it starts growth early in the spring even if the temperature is low. In the northern counties, Troms and Finnmark, it is the most favorable strain so far tried.”

Several studies have been reported on the effects of latitude (and thus time of growing-season initiation and photoperiod effects) on different latitudinal ecotypes of timothy (Evans 1931, 1939; Evans and Allard 1934; Evans *et al.* 1935). They found that ecotypes from “northern Europe” remained vegetative or very slow to produce elongated stems and inflorescences under normal growing-season photoperiods in Ohio; however, when provided with extended daily photoperiods with supplemental artificial illumination, they readily produced an abundance of normal elongated stems producing seed heads (Evans and Allard 1934).

Somewhat opposite to the above findings of abnormal performance of timothy brought from northern to southern latitudes is the failure of mid-temperate-adapted timothy cultivars (and many other grass and legume strains) to survive winters to their full potential when taken from more southern latitudes, where they are adapted, to be grown at subarctic latitudes in Alaska (Klebesadel 1970, 1984, 1985a, 1985b, 1992a, 1992b, 1993c, 1993d, 1994c; Klebesadel and Dofing 1991; Klebesadel and Helm 1992).

That failure of mid-temperate-adapted forage ecotypes, regional strains, and cultivars to survive winters at subarctic latitudes also has a considerable basis in photoperiodic relationships. Those forages are subjected to an unaccustomed and insufficient term of short photoperiods/long nyctoperiods to cause them to undergo

adequate development of freeze tolerance prior to onset of freezing temperatures. In support of that premise, artificial provision of short daily photoperiods for several weeks prior to onset of winter at this location, thus providing pre-winter conditions resembling those that occur in their areas of origin, resulted in markedly enhanced winter survival of mid-temperate-adapted grasses (Klebesadel 1971, 1985b). Some other experiments conducted at northern latitudes with generally similar results are cited in those 1971 and 1985b reports.

Mason and Stout (1954) and Wilsie (1962) have summarized numerous reports that supply insights into the importance of harmony between the evolved genetic/physiological status of latitudinal ecotypes of plants and their accustomed seasonal climatic patterns; these relate directly to results in several of the experiments in this report.

### Native Alpine Timothy

In North America, alpine timothy occurs at upper elevations across the southern portion of Alaska and in the Rocky and coastal mountains of Canada and in several western states (Hitchcock 1950; Hulten 1968). The cylindrical, spike-like seed heads of both timothies are similar in general appearance, but heads of alpine timothy tend to be of larger diameter than those of common timothy. Other major distinctions between the two species in general appearance are (a) a more inflated topmost leaf sheath in alpine timothy than in common timothy, and (b) culms (stems) of the alpine species tend to be more geniculate or spreading while those of common timothy are more erect (Fig. 5).

The general occurrence of alpine timothy in this area of Alaska with inherent subarctic adaptation suggested that the species merited evaluation for agronomic potential as a cropland forage.

### These Experiments

Despite generally good winterhardiness of far-north European timothy strains and cultivars in some farm practice and experimental studies in Alaska (Klebesadel 1970, 1992a, 1993c, 1993d; Klebesadel and Dofing 1991), those most winterhardy timothy cultivars nonetheless also have sustained severe winter injury or total winterkill in other investigations at this location (Klebesadel 1992b, 1994b, 1994c; Klebesadel and Helm 1992). Therefore, a better understanding was needed of factors, both physiological and managerial, that influence winter survival of this valuable forage species in Alaska.

Objectives of the nine experiments summarized in this report were (a) determine the comparative potentials and limitations of two species of timothy (alpine and common) for winterhardiness and forage production in southcentral Alaska, (b) evaluate agronomic performance of numerous North American and European cultivars and strains of common timothy for suitability for use in this area, (c) investigate and compare among cultivars from diverse latitudinal origins certain physiological and morphological characteristics that may be associated with successful versus unsuccessful winter survival in Alaska, (d) compare different planting dates and various dates of seeding-year harvest for seeding-year forage production



Figure 5. Two-year-old individual plants of (left) native Alaskan alpine timothy (*P. alpinum*) and (right) typical plant of Climax common timothy (*P. pratense*). Note relative paucity of culms and total herbage in the alpine timothy plant. Numbers on stake indicate height in feet.

and for effects on subsequent winter survival, and (e) determine forage productivity of established timothy harvested on various schedules and frequencies and ascertain effects of those various harvest-management options on subsequent winter survival.

Five of the nine experiments summarized in this bulletin (Exps. II through VI) were reported previously in a technical journal (Klebesadel and Helm 1986); they have

been included in this report (a) to provide a more complete understanding of structure, physiology, and adaptation within the species, and (b) to create a more complete and comprehensive exposition of the performance and potential usefulness of timothy in this area. Because this publication will be more available and relevant to Alaska growers, yields reported in metric units in the journal report have been converted to English units herein.

Table 1. Percent winter survival in 50-plant lots, grown as individual plants in rows, of timothy cultivars from Norway, Sweden, Finland, Denmark, and Canada; and in 25-plant lots of alpine timothies from Alaska and Iceland (Exp. I).

Source	Cultivar or strain	Percent winter survival	Mean injury rating of surviving plants <sup>1</sup>
Common timothy ( <i>P. pratense</i> ):			
NORWAY	Vågönes	100	4.8
	Bodin	98	4.7
	Engmo <sup>2</sup>	96	4.4
	Gammelsröd	90	6.5
	Bjorneby	88	6.2
	Grinstad	86	5.6
	Åsnes	86	7.5
	Steen	84	5.4
	Sundby	84	5.8
	Forus	<u>84</u>	<u>6.6</u>
	Mean	90	5.8
SWEDEN:	0841	100	3.2
	Bottnia II	98	5.5
	Kampe II	84	5.8
	Bottnia	84	6.5
	W:S T-41	<u>24</u>	<u>7.9</u>
	Mean	78	5.8
FINLAND:	Nivala	96	5.0
	Tarmo	96	5.0
	Lappi <sup>3</sup>	96	5.6
	Tammisto <sup>2</sup>	91	5.8
	Hankila	<u>78</u>	<u>6.9</u>
Mean	91	5.7	
DENMARK:	Otofte II	94	5.0
	Otofte	<u>71</u>	<u>7.2</u>
	Mean	83	6.1
CANADA:	Climax <sup>4</sup>	49	7.6
Alpine timothy ( <i>P. alpinum</i> )			
ALASKA:	Lot 259 (Unalaska Is.)	0	-
	Lot 260 (Cold Bay)	0	-
	Lot 261 (Umnak Is.)	0	-
ICELAND:	Lot 440 <sup>5</sup>	0	-

<sup>1</sup>Injury ratings: 1 = no injury, 9 = severely injured.

<sup>2</sup>Means of three, 50-plant lots.

<sup>3</sup>Means of two, 50-plant lots.

<sup>4</sup>Climax appeared as 5-plant check lots between all other pairs of lots; Climax winter-survival mean based on about 130 plants.

<sup>5</sup>A 50-plant lot.

These experiments were conducted at the University of Alaska Agricultural and Forestry Experiment Station's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska.

## EXPERIMENTAL PROCEDURES

In each field experiment except Exp. I, commercial fertilizer disked into plowed Knik silt loam (Typic Cryochrept) seedbeds before planting supplied N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O at 32, 128, and 64 lb/A, respectively. All experimental sites were selected for good surface drainage, and no companion crops were planted except in Exps. VIII and IX. With all broadcast-seeded plots, planting rates were adjusted on the basis of germination trials to plant grasses at the following rates in lb/A: timothy 8, Polar bromegrass (predominantly *Bromus inermis* Leyss. X *B. pumpellianus* Scribn.) 22, Garrison creeping foxtail (*Alopecurus arundinaceus* Poir.) 16, Nugget Kentucky bluegrass (*Poa pratensis* L.) 20, and Arctared red fescue (*Festuca rubra* L.) 20.

Individual broadcast-seeded plots measured 5 by 18 or 5 by 20 feet. Randomized complete block

experimental designs with four replications were used in all row and broadcast-seeded plot tests except Exp. I which was not replicated, and Exp. 2, which utilized three replications. In each field test except Exp. I, a pre-emergence application of dinoseb (dinitro-o-sec-butylphenol) was sprayed in water solution uniformly onto each seedbed 1 to 4 days after planting to control broadleaf weeds.

With all forage harvests from broadcast-seeded plots, yields were derived from a swath 30 inches wide mowed from the centerline of each plot after a strip 15 inches wide was mowed and discarded from both ends of all plots to remove border effects. Mowing was done with a sickle-equipped plot mower leaving approximately a 2 1/2-inch stubble. Small, bagged samples from each plot were dried to constant weight at 60°C (140°F). All forage yields are reported on the oven-dry basis. Commercial fertilizer supplying N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O at the rate of 126, 96, and 48 lb/A was topdressed in early spring of each year that two harvests were taken in Exps. II, III, and IV. Ammonium nitrate supplying N at 84 lb/A was topdressed 1 to 3 days after the first-cutting forage harvest in all broadcast-seeded plots harvested twice per year.

Table 2. Seeding-year and subsequent forage yields of timothy cultivars from diverse latitudinal origins, and four very winterhardy, rhizomatous forage grass cultivars. Planted 25 June 1970 (Exp. II).

Source	Cultivar or selection	1970 22 Sep	1971		1972		1973		1974		1975		Total
			8 July	7 Oct	5 July	18 Oct	11 July	12 Sep	27 June	10 Sep	26 June	19 Sep	
		Oven-dry tons per acre											
Norway	Engmo	0.21 c <sup>1</sup>	0.10 b	1.65 bc	1.07 c	0.47 c	0.95 cd	0.49 d	2.20 ab	0.19 c	0.31 d	1.42 bc	9.06 b
Iceland	Korpa	0.26 c	0.22 b	1.80 ab	0.85 c	0.49 c	0.92 d	0.55 cd	2.17 ab	0.08 d	1.45 bc	0.68 c	9.47 b
Finland	Tammisto	0.93 ab	Tr <sup>2</sup>	0.51 d	Tr	Tr	Tr	Tr (wk) <sup>3</sup>	—	—	—	—	1.44 c
Sweden	Bottnia II	0.96 ab	Tr	0.63 d	Tr	0.02 d	Tr	0.16 e	0.81 c	Tr	Tr	0.65 c	3.23 c
	Omnia	0.85 ab (wk)	—	—	—	—	—	—	—	—	—	—	0.85 c
	W:S T-48	0.73 ab (wk)	—	—	—	—	—	—	—	—	—	—	0.73 c
	W:S T-49	0.42 c (wk)	—	—	—	—	—	—	—	—	—	—	0.42 c
Canada	Climax	1.02 a (wk)	—	—	—	—	—	—	—	—	—	—	1.02 c
USA	Wisconsin T-10	1.06 a (wk)	—	—	—	—	—	—	—	—	—	—	1.06 c
Checks	Polar bromegrass	0.11 c	0.12 b	1.13 cd	2.22 b	0.62 c	2.94 a	0.62 cd	2.96 a	0.17 cd	2.10 ab	1.95 b	14.94 a
	Garrison creeping foxtail	0.98 ab	0.07 b	1.66 bc	3.17 a	0.75 c	2.85 ab	0.77 c	2.89 a	0.35 bc	2.68 a	1.36 bc	17.53 a
	Nugget Kentucky bluegrass	0.16 c	1.90 a	2.45 a	2.05 b	1.73 a	1.91 bc	1.37 a	1.94 b	0.95 a	1.33 c	2.90 a	18.69 a
	Arctared red fescue	0.54 bc	1.85 a	1.58 bc	2.04 b	1.26 b	2.51 ab	1.05 b	2.68 ab	0.56 b	1.71 bc	1.66 b	17.44 a

<sup>1</sup>Within each column, means not followed by a common letter differ significantly (5% level) using Duncan's Multiple Range Test.

<sup>2</sup>Trace amount of herbage inadequate for harvestable yield.

<sup>3</sup>Stand winterkilled completely.

## Experiment I

### Winter Survival of Two Species of Timothy as Individual Plants in Rows

This experiment compared 22 cultivars of common timothy from Norway, Sweden, Finland, and Denmark with one from Canada as a standard or check. Included also were four collections of alpine timothy, three from Alaska and one from Iceland. All seed lots were planted in a soil/sand/peat mixture in plant bands in greenhouse flats in April, 1958. At the small seedling stage, they were thinned to one seedling per band. In June, all plants were transplanted to the field into a plowed seedbed using a tractor-mounted transplanter that placed plants approximately 24 inches apart in

rows 3 feet apart. An aliquot of liquid fertilizer solution was dispensed into the soil furrow beneath each plant at transplanting. The planting consisted of unreplicated, randomly distributed, mostly 50-plant lots of the 22 cultivars (identified in Table 1), with 5-plant check lots of Climax timothy from Canada appearing in the row between all other cultivar lots. Each cultivar appeared as a single 50-plant lot except for Engmo and Tammisto, each of which were planted in three, 50-plant lots, and Lappi which appeared in two, 50-plant lots; these multiple entries were to compare different seed sources of the latter three cultivars. Each of the three alpine timothies from Alaska appeared as a 25-plant lot, while the one from Iceland consisted of 50 plants.

Table 3. Seeding-year forage yields, percent winter survival, and second-year forage yields of 17 timothy cultivars and selections from diverse latitudinal origins and two non-timothy check cultivars. Planted 17 June 1974 (Exp. III).

Source	Cultivar or selection	Forage yield 3 Oct 1974 Oven-dry tons/A	Winter survival <sup>1</sup>		Forage yields - 1975		
			Two snow-covered replicates	Two exposed replicates	16 June	18 Sep	Total
			Percent				
Norway	Bodin	0.61 ef <sup>2</sup>	100 a	80 bc	1.94 ab	2.52 a-d	4.46 ab
	Engmo	0.86 cde	100 a	95 ab	1.93 ab	2.40 a-d	4.33 ab
	Va-BL-60	0.52 f	100 a	98 a	1.86 ab	2.34 a-d	4.20 ab
	Mean	0.66	100	91	1.91	2.42	4.33
Iceland	Korpa	0.13 g	100 a	100 a	2.03 ab	2.44 a-d	4.47 ab
Finland	Tammisto	1.24 ab	88 ab	65 cd	1.34 bc	2.98 ab	4.32 ab
Sweden	Bottnia II	0.97 bcd	100 a	60 d	1.23 bcd	3.07 a	4.30 ab
	Omnia	0.90 cde	65 cd	23 e	0.66 cde	2.74 abc	3.40 abc
	W:S T-59	0.17 g	60 cd	5 fg	0.48 de	2.20 a-d	2.68 bcd
	Mean	0.68	75	29	0.79	2.67	3.46
Canada	Climax	1.39 a	78 bc	10 efg	0.72 cde	2.49 a-d	3.21 abc
	Drummond	0.49 f	50 d	13 efg	0.44 de	2.73 abc	3.17 abc
	Milton	0.83 de	63 cd	5 fg	0.47 de	2.64 abc	3.11 abc
	Mean	0.90	64	9	0.54	2.62	3.16
USA	Mor-Tim	1.26 ab	65 cd	23 e	0.59 cde	2.86 ab	3.45 abc
	Itasca	1.16 abc	65 cd	20 ef	0.55 cde	2.87 ab	3.42 abc
	Wisconsin T-10	1.15 abc	63 cd	8 efg	0.53 cde	2.70 abc	3.23 abc
	Lilly's Best	0.52 f	20 e	1 g	0.16 e	1.77 bcd	1.93 cd
	Essex	0.01 g	73 bc	8 efg	0.12 e	1.28 d	1.40 d
	Clair	0.93 cd	13 e	1 g	0.02 e	1.27 d	1.29 d
	Mean	0.84	50	10	0.33	2.13	2.45
Checks	Polar bromegrass	0.77 def	100 a	98 a	1.98 ab	2.57 abc	4.55 a
	Garrison creeping foxtail	0.78 def	100 a	100 a	2.34 a	1.53 cd	3.87 ab

<sup>1</sup>Visual estimates for each plot, 5 June 1975 (% survival of stand present in autumn 1974). All timothy cultivars winterkilled 100% during winter 1975-1976, while both rhizomatous check cultivars sustained no apparent winter injury.

<sup>2</sup>Within each column, means not followed by a common letter differ significantly (5% level) using Duncan's Multiple Range Test.

## Experiment II

### Forage Yields and Winter Survival of Nine Timothy Strains in Broadcast–Seeded Plots

Timothy cultivars or strains from diverse latitudinal sources in North America and northern Europe

(listed in Table 2) were planted on 25 June 1970; four check cultivars of other grass species were included. Seeding–year and subsequent forage yields over the following five years were harvested on dates shown in Table 2.

Table 4. Seeding-year and subsequent oven-dry forage yields, late-season dormancy, and winter survival of 23 timothy cultivars from northern Europe, Canada, and the USA, and four non-timothy check cultivars. Planted 11 July 1979 (Exp. IV).

Source	Cultivar or selection	1979	1980			1981			Dormancy <sup>1</sup>	1982	
		12 Oct	24 June	18 Sep	Total	22 June	17 Sep	Total		Winter survival <sup>2</sup>	30 June
		Tons/A						%	Tons/A		
Norway	Engmo	0.80 f-i <sup>3</sup>	2.81 abc	1.18 h	3.99 cde	2.47 ab	1.87 gh	4.34 a-f	1.8	86	1.95 b
Iceland	Korpa	1.17 a-d	2.74 bcd	1.30 gh	4.04 cde	2.67 a	2.07 d-h	4.74 ab	1.3	82	1.71 b
Finland	Jo-0182	1.28 abc	2.53 c-f	1.67 d-g	4.20 bc	2.47 ab	2.49 a-f	4.96 a	1.8	59	1.25 cde
	Hja-1277	1.07 b-g	2.64 b-e	1.43 fgh	4.07 b-e	2.19 a-e	2.12 c-h	4.31 a-f	1.5	56	1.16 def
	Jo-0166	1.25 abc	2.53 c-f	1.57 e-h	4.10 b-e	2.13 a-f	2.54 a-f	4.67 abc	1.8	46	1.03 efg
	Jo-1014	0.99 c-h	2.51 c-f	1.36 fgh	3.87 c-f	2.25 a-d	2.33 b-g	4.58 a-e	2.0	52	0.92 e-h
	Tarmo	1.10 a-f	2.40 d-g	1.44 fgh	3.84 c-f	2.27 abc	2.47 a-f	4.74 ab	2.0	51	0.92 e-h
	Tiiti	1.26 abc	2.14 g-j	1.95 a-e	4.09 b-e	2.30 abc	2.45 a-g	4.75 ab	2.3	37	0.85 e-i
	Tammisto	<u>1.11</u> a-f	<u>2.36</u> e-h	<u>1.55</u> e-h	<u>3.91</u> c-f	<u>1.95</u> a-h	<u>2.26</u> b-h	<u>4.21</u> a-f	<u>2.3</u>	<u>40</u>	<u>0.73</u> f-j
	Mean	1.15	2.44	1.57	4.01	2.22	2.38	4.60	2.0	49	0.98
Sweden	Bottnia II	0.60 i	2.92 ab	1.65 d-g	4.57 ab	2.26 a-d	2.39 a-g	4.65 a-d	2.0	42	0.87 e-i
	Astra	1.42 a	1.87 jkl	2.04 a-d	3.91 c-f	1.41 f-k	2.57 a-e	3.98 b-g	3.5	17	0.44 i-l
	WW T49	1.15 a-e	1.87 jkl	1.94 a-e	3.81 c-f	1.51 e-k	2.73 abc	4.24 a-f	2.0	14	0.37 jkl
	Omnia	<u>0.84</u> e-i	<u>1.50</u> m	<u>1.94</u> a-e	<u>3.44</u> fg	<u>0.85</u> kl	<u>2.85</u> ab	<u>3.70</u> efg	<u>2.8</u>	<u>9</u>	<u>0.22</u> kl
	Mean	1.00	2.04	1.89	3.93	1.51	2.64	4.14	2.6	21	0.48
Canada	Champ	1.26 abc	2.08 g-k	2.06 a-d	4.14 b-e	1.66 c-j	2.58 a-e	4.24 a-f	4.3	31	0.73 f-j
	Milton	1.33 ab	2.01 h-k	2.15 abc	4.16 bcd	1.50 e-k	2.67 a-d	4.17 a-f	3.8	36	0.66 g-k
	Basho	1.42 a	1.81 j-m	2.17 abc	3.98 cde	1.32 g-l	3.00 a	4.32 a-f	4.3	17	0.44 i-l
	Climax	1.20 abc	1.75 klm	2.24 ab	3.99 cde	1.13 i-l	2.62 a-e	3.75 d-g	4.5	27	0.39 jkl
	Drummond	<u>1.16</u> a-e	<u>1.09</u> n	<u>1.99</u> a-e	<u>3.08</u> gh	<u>0.65</u> l	<u>2.56</u> a-f	<u>3.21</u> g	<u>4.0</u>	<u>6</u>	<u>0.17</u> l
	Mean	1.27	1.75	2.12	3.87	1.25	2.69	3.94	4.2	23	0.48
USA	Itasca	1.32 abc	1.97 ijk	2.10 a-d	4.07 b-e	1.92 b-i	2.61 a-e	4.53 a-e	2.8	36	0.77 f-i
	Mor-Tim	1.40 ab	2.06 g-k	2.17 abc	4.23 bc	1.22 h-l	2.82 ab	4.04 a-g	3.3	27	0.47 h-l
	Verdant	1.35 ab	1.74 klm	1.98 a-e	3.72 c-f	1.20 i-l	2.60 a-e	3.80 c-g	3.3	19	0.32 jkl
	Lilly's Best	0.68 hi	0.55 o	2.19 abc	2.74 h	0.61 l	2.83 ab	3.44 fg	3.5	11	0.22 kl
	Clair	<u>1.30</u> abc	<u>1.57</u> lm	<u>2.29</u> a	<u>3.86</u> c-f	<u>0.82</u> kl	<u>2.68</u> a-d	<u>3.50</u> fg	<u>4.8</u>	<u>4</u>	<u>0.12</u> l
	Mean	1.21	1.58	2.15	3.72	1.15	2.71	3.86	3.5	19	0.38
Checks	Polar bromegrass	0.86 d-i	3.09 a	1.81 b-f	4.90 a	2.15 a-e	2.01 e-h	4.16 a-f	1.3	75	1.63 bc
	Garrison creeping foxtail	0.86 d-i	2.58 b-f	1.46 fgh	4.04 cde	2.04 a-g	1.96 fgh	4.00 b-g	1.1	100	2.58 a
	Nugget Kentucky bluegrass	0.61 i	1.93 ijk	1.74 c-g	3.67 def	1.52 d-k	2.62 a-e	4.14 a-f	1.0	100	1.55 bcd
	Arctared red fescue	0.76 ghi	2.26 f-i	1.37 fgh	3.63 ef	2.28 abc	1.69 h	3.97 b-g	1.0	90	1.66 bc

<sup>1</sup>Visual rating of height of regrowth 8 days after second cutting: 1 = 0-2 cm, 2 = 2-4 cm, 3 = 4-6 cm, 4 = 6-8 cm, and 5 = 8-10 cm.

<sup>2</sup>Visual estimates 22 June 1982.

<sup>3</sup>Within each column, means not followed by a common letter differ significantly (5% level) using Duncan's Multiple Range Test.

### **Experiment III**

#### **Forage Yields and Winter Survival of 17 Timothy Strains in Broadcast–Seeded Plots**

Timothy cultivars from Norway, Sweden, Finland, Iceland, Canada, and the conterminous U.S., and Polar bromegrass and Garrison creeping foxtail, included for comparison, were seeded on 17 June 1974. Seeding–year and subsequent forage harvests were taken on dates listed in Table 3.

### **Experiment IV**

#### **Forage Yields and Winter Survival of 23 Timothy Strains in Broadcast–Seeded Plots**

Timothy cultivars from Norway, Sweden, Finland, Iceland, Canada, and the conterminous U.S., and Polar bromegrass, Garrison creeping foxtail, Nugget Kentucky bluegrass, and Arctared red fescue, included for comparison, were planted on 11 July 1979. Seeding–year and subsequent forage harvests were taken on dates listed in Table 4.

### **Experiment V**

#### **Pre–Winter Dry–Matter Concentration and Food–Reserve Storage in Overwintering Tissues of Cultivars Adapted at Diverse Latitudes**

Three timothy cultivars of diverse latitudinal adaptation (Engmo, Climax, and Clair) were seeded in rows in June of two consecutive years in two separate experiments (Va and Vb) for the purpose of determining changes in percent dry matter and food–reserve levels in overwintering storage tissues at progressively later dates during the latter portion of the seeding–year growing season. Dates of planting; procedures for planting, sampling, and plant preparation; and measurement techniques were described in Exp. 4 of an earlier report (Klebesadel 1985a). Dates of sampling from the field were 10 August, 30 August, and 10 October in Exp. Va, and 22 August, 18 September, and 10 October in Exp. Vb.

Some spaced plants in rows from the same seedings were left in the field to determine actual percent winter survival of cultivars and to relate these data to dry–matter changes and reserve storage measurements. Averaged over both years, there were 84 plants per row on which winter survival data were determined.

### **Experiment VI**

#### **Freeze Tolerance During the Cold–Hardening Period of Cultivars Adapted at Diverse Latitudes**

Three timothy cultivars (Engmo, Climax, and Clair) were seeded in rows 2 feet apart and 18 feet long on 10

June 1974. On 30 October 1974, aerial growth was severed to preclude any further transpirational loss of water from plants; immediately thereafter plants were dug from each row. Cold water was used to wash soil from roots, then plant crowns were broken apart to obtain individual tillers. All roots were severed from tiller bases and outer leaves were removed to expose corms; tiller growth beyond 1 inch above the base of each corm was severed and discarded. Corms were rinsed in a cold–water spray to remove all traces of soil and debris, rinsed three times in distilled water, and dried of surface moisture.

Five–gram samples of prepared corms (exact weight achieved by corm selection and tiller trimming) were placed into a 2.5 by 20–cm stoppered test tube and frozen for 20 hours. Separate samples of each cultivar were frozen at  $-12^{\circ}$ ,  $-24^{\circ}$ , and  $-36^{\circ}\text{C}$  ( $+10.4^{\circ}$ ,  $-11.2^{\circ}$ , and  $-32.8^{\circ}\text{F}$ ). After freezing, test tubes were placed in a refrigerator for 4 hours for temperature equilibration before 50 ml of refrigerated, distilled water were added to each. Test tubes were replaced into the refrigerator for 20 hours for diffusion of cell electrolytes from freeze–injured plant cells. Decanted water was brought to  $25^{\circ}\text{C}$  ( $77^{\circ}\text{F}$ ) and specific conductivities determined for each sample according to the method described by Dexter *et al.* (1932). Water samples were returned to their specific test tubes containing corms; all were boiled for 5 minutes in a common water–bath to effect complete destruction of plant cells in the overwintering tissues. Samples were again left to diffuse for 20 hours before repeat decanting, equilibration at  $25^{\circ}\text{C}$ , and a second specific conductivity measurement on each sample. The ratio of specific conductivity following freezing to specific conductivity following boiling (maximum injury possible) is presented as percent injury induced by freezing in corm tissues.

### **Experiment VII**

#### **Effects of Planting Dates and Seeding–Year Harvest Dates on Seeding–Year Forage Yields and on Subsequent Winter Survival and Spring Forage Yield**

Engmo timothy was broadcast–seeded in three large, adjacent blocks in 1980 on 16 May, 1 June, and 19 June. Six different seeding–year forage harvests were taken in each of the four replicates in each block at about 10–day intervals on the following dates: 22 August; 2, 11, and 23 September; and 1 and 9 October. All plots were trimmed to a uniformly short (about 2 1/2–inch) stubble height after killing frost to prevent uneven snow retention on plots. On 20 April 1981, N,  $\text{P}_2\text{O}_5$ , and  $\text{K}_2\text{O}$  were topdressed uniformly over all plots at the rate of 126,

96, and 48 lb/A, respectively. All plots were harvested on 18 June to provide a uniform measure of the effects of planting dates and seeding–year harvest dates on vigor and productivity of stands in the second year.

## Experiments VIII and IX

### Effects of a Broad Array of Harvest Schedules and Frequencies on Forage Production and on Subsequent Winter Survival of Established Timothy

Two similar 3-year experiments were conducted with Engmo timothy (a) seeded the first year with a companion crop of barley (*Hordeum vulgare* L.), (b) subjected in the second year to a broad array of harvest schedules and frequencies, and (c) all treatments harvested on the same day in late June or early July of the third year, with forage yield in that harvest representing an evaluative measure of the effects of harvest treatments in the previous year on subsequent stand health and productivity.

The two experiments were planted 6 June 1980 and 17 June 1982. The companion crop of Weal barley was sown with a small, tractor-mounted drill that planted 10 drill rows six inches apart; barley sowing rate was about 40 lb/A, an intentionally lighter rate than for a grain crop in order to decrease competitive effects on the timothy seedlings. Timothy was seeded at the same time with a towed-behind corrugated-roller seeder.

In early August of both 1980 and 1982, the barley companion crop was clipped to a 10-inch stubble and raked off the field. The tall stubble was left in place over winter to hold a protective, insulating snow cover against the removal force of winter winds, thus to promote enhanced winter survival of the timothy seedlings (see Fig. 6 in Klebesadel 1992a). That stubble was clipped and removed from both experimental areas in early spring of the year after establishment.

In Exp. VIII, spring fertilizer topdressings of N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O at 126, 96, and 48 lb/A, respectively, were applied 20 April 1981 and 6 May 1982. In Exp. IX, the same rates were applied 23 May 1983 and 7 May 1984. A mid-season topdressing of N at 84 lb/A in the year of differential harvests was applied 7 July 1981 in Exp. VIII and 8 July 1983 in Exp. IX.

The differential harvests in both experiments, a broad array of cutting schedules and frequencies that included 5, 4, 3, and 2 cuttings per year, involved 34 treatments in Exp. VIII and 40 in Exp. IX. Actual harvest dates for the two experiments appear in figures that accompany discussion of the results of those experiments.

Within each set of harvest frequencies (2, 3, 4, or 5 cuts per year), final harvest dates were progressively later

in the growing season by about 10-day increments. As final cuttings were progressively later, more days generally were allowed for regrowth between cuttings. The latest final harvest date in Exp. IX (trtmts. 6, 11, 16, 24, 32, 40) was intended to be 30 September but was advanced to the 26th because a low of 24°F was recorded on 24 September, and precipitation was predicted for 27–28 September that could have been snow (but wasn't) that could have precluded harvest on 30 September.

In the year following the year of differential harvests, all plots were harvested on the same date (23 June 1982 in Exp. VIII, 2 July 1984 in Exp. IX) to evaluate the effects of the various cutting schedules and frequencies, conducted during the previous years, on subsequent winter survival and following-year productivity.

## RESULTS AND DISCUSSION

### Experiment I

#### Winter Survival of Two Species of Timothy as Individual Plants in Rows

All transplants established well, and notes on phenology, leafiness, growth habit, winter injury and winter survival were recorded on all plants for three consecutive growing seasons. The first winter was more severe than the second, and percent winter survival of cultivars and injury ratings of surviving plants following the first winter are presented in Table 1. No appreciable winterkill of plants occurred during the milder second winter.

Alpine timothy is a relatively depauperate, unthrifty plant in its native habitat, offering little evidence of agronomic potential. However, the same is true of Siberian wildrye (*Elymus sibiricus* L.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), arctic wheatgrass (*A. sericeum* Hitchc.) and pumpelly bromegrass (*Bromus pumpellianus*) in native habitats in Alaska, but they respond dramatically in increased herbage production when grown on fertilized cropland soils (Klebesadel 1993c, 1994a, 1994b).

All plants in the four lots of alpine timothy (3 Alaskan, 1 Icelandic) winterkilled during the first winter. Moreover, a comparison of *P. alpinum* and *P. pratense* plants in another test at the end of their second year of growth (Fig. 5) provided further evidence of the relatively poor forage potential in alpine timothy with its few culms per plant, short growth, minimal leafiness, and meager total herbage, even with addition of abundant fertilizer nutrients. Inasmuch as all four lots were from north-latitude sources but winterkilled 100%, that species was dropped from further consideration as a potential cropland forage for Alaska, despite the inherent

north–latitude adaptation of the four collections evaluated.

It should be noted that the collection sites for the three Alaska alpine timothy lots evaluated were in maritime, southwestern areas of the state that experience relatively mild winter stresses compared with the test site in the Matanuska Valley. The Icelandic collection fared no better.

The sites occupied by alpine timothy generally are on mountain slopes and in high meadows (Aamodt and Savage 1949; Hulten 1968). Although all mountainous habitats might be assumed to be universally stressful winter environments, in fact the range of habitats occupied by plants at high elevations actually represent a broad array of exposures to winter stresses. On exposed, windswept slopes, only the most winterhardy of species can survive.

However, other mountain habitats such as meadows and “snow patch” sites where alpine timothy occurs, receive protective, insulating snow cover early and it remains in place all winter. Such habitats expose plants to far less rigorous winter stresses than occur in open, windswept farm fields.

These poor winter–survival results with subarctic–adapted alpine timothy tend to parallel agronomic–evaluation experience with certain other native Alaska plant ecotypes that similarly grow in relatively protected winter habitats and survive winters poorly when subjected to the much more stressful winter exposure in an open field environment where strong winter winds often blow away the protection of an insulating snow cover (Dale 1956; Klebesadel 1974). Examples are native Alaskan large–leaved lupine (*Lupinus polyphyllus* Lindl.) and a tall–growing grass, drooping woodreed (*Cinna latifolia* (Trev.) Griseb.); these grow commonly in woodlands in southcentral Alaska where insulating snow cover remains in place. Despite their inherent subarctic adaptation, when those plants have been grown in experiments in the more stressful and exposed winter environment of cropland fields, they have winterkilled 100% (Klebesadel 1993d; also unpublished information, Alaska Agric. and Forestry Exp. Sta.).

The cultivars of common timothy from Norway, Sweden, Finland, and Denmark showed good to excellent winter survival (Table 1). All except W:S T–41 from Sweden surpassed the check cultivar Climax, from Canada, in winter survival. Moreover, surviving plants of most cultivars from northern Europe showed less evidence of winter injury than the less winterhardy, more southern–adapted Climax. Thus, cultivars with best winter survival tended to exhibit less injury in the plants that survived the winter and vice versa (Table 1).

## Experiment II

### Forage Yields and Winter Survival of Nine Timothy Strains in Broadcast–Seeded Plots

Seeding–year forage yields harvested on 22 September differed significantly among timothy strains (Table 2). The southernmost–adapted cultivars, Climax and Clair, yielded over 1 T/A, while the northernmost–adapted Engmo and Korpa produced less than 1/4 T/A. The intermediate–latitude–adapted timothy strains and the four non–timothy grasses produced yields intermediate between those extremes.

The winter of 1970–71 was severe in causing plant mortality in this and other experiments in progress then. Timothy strains that winterkilled totally in Exp. II during that first winter were Omnia, W:S T–48, and W:S T–49 from Sweden, Climax from Canada, and Wisconsin T–10 (Table 2).

Bottnia II from Sweden, and Tammisto from Finland sustained such severe winter injury that no forage yields were obtained in the first cutting in 1971 and only modest yields (mean = 0.57 T/A) in the second cutting. Thereafter, Bottnia II produced small yields in only four of the subsequent eight cuttings. The severely winter–injured and thinned stands of Tammisto produced no recoverable yields before all plots of that cultivar succumbed totally during the winter of 1973–74.

In the spring following the severe winter of 1970–71, the non–timothy check grasses also showed a wide range of winter injury. The very winterhardy Polar bromegrass and Garrison creeping foxtail sustained winter injury also and produced very low first–cut yields in 1971. In contrast, the extremely winterhardy Nugget Kentucky bluegrass and Arctared red fescue were the least injured of all 13 grass strains compared, each producing almost 2 T/A in the first cutting of 1971.

The four grasses that sustained less winter injury than the timothy strains all have better protected overwintering tissues. Smooth bromegrass, creeping foxtail, Kentucky bluegrass, and red fescue have subterranean rhizomes (underground stems) that afford those plants better protection from winter stresses than timothy plants with their corms more exposed at the soil surface (Jung and Kocher 1974; Klebesadel 1992b, 1993d; Smith 1964b).

Both Engmo and Korpa produced harvestable forage yields in all 11 cuttings during the experiment; their highest yields were in the first cutting of 1974 when both surpassed 2 T/A. All grasses produced low yields in the second cutting of 1974 due to acutely sub–normal precipitation after mid–July of that year (Table 5). In general, yields of Engmo and Korpa differed little during

the six years; the greatest difference was in 1975 when Korpa produced considerably more in the first cutting and Engmo in the second.

Engmo and Korpa total yields for the experiment were about equal, averaging 9.27 T/A. However, those timothy yields were significantly lower than the total yields of the four non-timothy grasses that averaged over 17 T/A. Beyond winter injury in 1970–71 that severely injured Engmo and Korpa stands at the start of the experiment, timothy is acknowledged to be relatively shallow-rooted and drouth susceptible, compared with many other grasses (Grant and Burgess 1982; Hanson 1972; Lambda *et al.* 1949; McElroy and Kunelius 1995; Smith *et al.* 1986). Therefore, inasmuch as (a) normal precipitation in this area is marginal for realizing the forage–production potential of timothy, (b) three of the six years of this experiment were below normal in precipitation (Table 5), and (c) timothy productivity is curtailed by drouthiness more than many other grasses, the modest yields of even the best timothies were not surprising.

A clear pattern of winterhardiness related to latitudinal adaptation was apparent. Of the nine cultivars, Engmo and Korpa adapted at 64° to 70°N in Norway and Iceland, respectively, exhibited best winter survival. Tammisto from Finland and Bottnia from Sweden, adapted at 55.5° to 62°N, were poor but intermediate in survival. The three other Swedish cultivars, Climax from about 45°N in Canada, and Wisconsin T–10 from near 43°N were poorest in winterhardiness.

### Experiment III

#### Forage Yields and Winter Survival of 17 Timothy Strains in Broadcast–Seeded Plots

The year of establishment of this experiment (1974) was markedly below normal in precipitation (Table 5). However, all but six of the 17 timothy strains developed full, adequate stands. Visual estimates of percents of full stands for those six strains in September, 1974, were: Essex 10 to 20%, Korpa and Lilly’s Best 30 to 40%, W:S T–59 and Drummond 40 to 50%, and Clair 80%. Those thin stands resulted in low seeding–year forage yields (Table 3).

Seeding rates had been adjusted on the basis of germination tests to seed all strains at the same rate of pure live seed. It is believed that poor seedling vigor in the 6– to 9–year–old seed lots of the strains that developed poor stands, exacerbated by low precipitation amounts, contributed to the thin stands of the above strains.

The location of this experiment, in the lee of a wooded tract from strong winter winds, resulted in marked differences in snow cover on the two halves of the experiment. That happenstance contributed valuable information on (a) the beneficial effect of snow cover in insulating timothy stands from the harmful effects of low air temperatures, and (b) the differences in winter survival of the various timothy strains under two different levels of exposure to winter stresses. Other reports on the considerable differences in winter survival of forages as influenced by insulating snow cover versus its absence

have appeared previously (Klebesadel 1992a; Klebesadel and Dofing 1991).

Two of the replicates remained covered by snow during much of the winter of 1974–75, while wind swept the other two bare of snow cover; the result was markedly different winter survival of most timothy cultivars in the two halves of the experiment (Table 3).

All timothy strains except Lilly’s Best (20%) and Clair (13%) from the conterminous U.S. exhibited 50% survival or better where snow cover had protected stands. In that half of the experiment, Bodin, Engmo, and Va–BL–60 from Norway, Korpa from

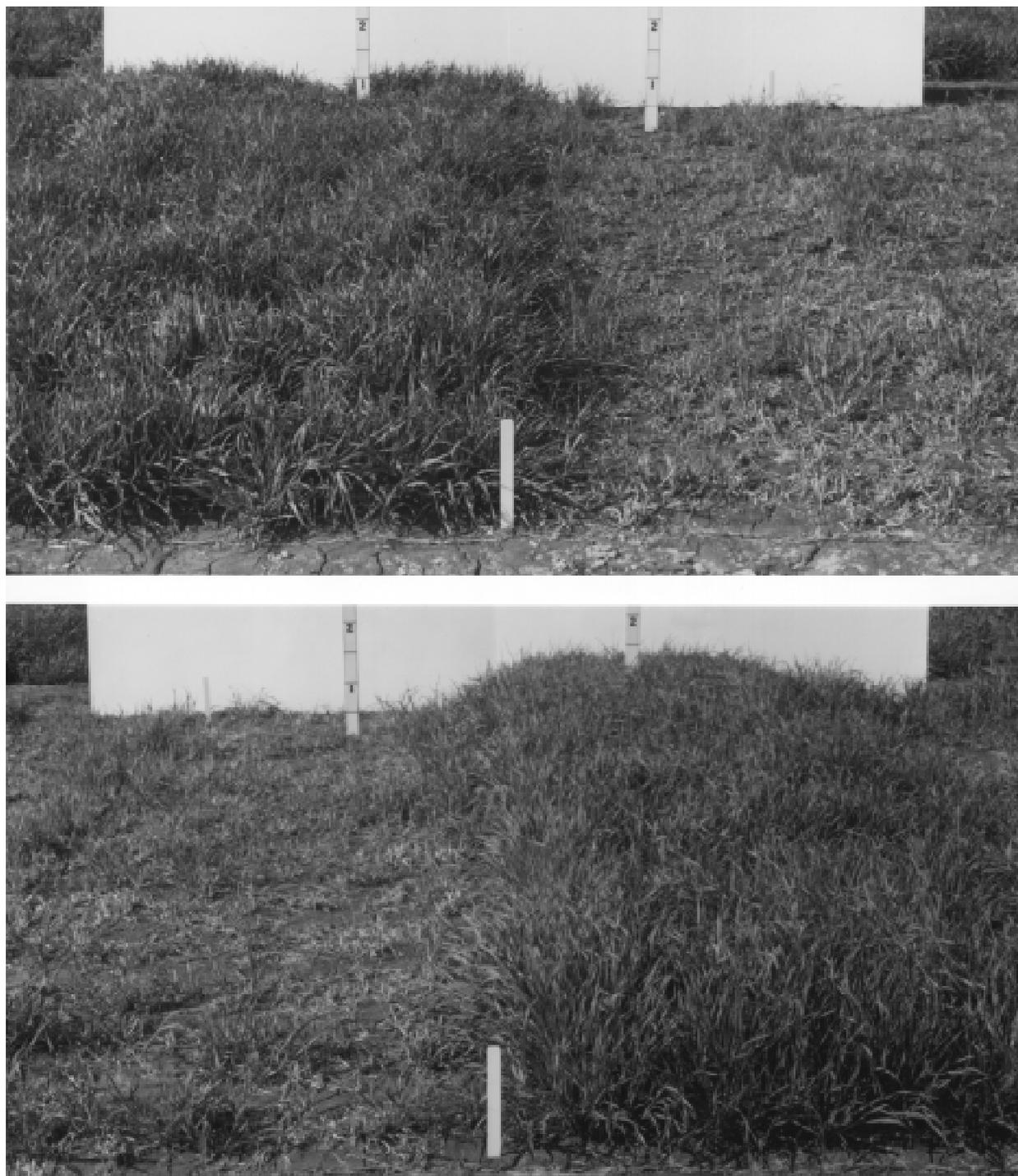
Table 5. Monthly departures (inches) from normal of precipitation recorded at the Matanuska Research Farm during the course of experiments discussed in this report.

Experiments	Year	Apr	May	June	July	Aug	Sep	Departure
I	1958	+0.05	-0.02	-0.08	-0.04	-1.78	-1.51	-3.38
	1959	+1.74	+0.36	-0.45	+2.65	+3.13	-1.22	+6.21
II and III	1970	-0.05	-0.66	+0.06	-0.36	-0.75	-1.55	-3.31
	1971	+0.59	-0.47	+0.49	-0.14	+2.00	+0.09	+2.56
	1972	+0.18	+0.49	+0.05	-0.64	-1.85	+2.54	+0.77
	1973	+0.69	-0.36	+0.32	-2.04	+1.66	-1.50	-1.23
	1974	+0.12	+0.06	-0.94	-1.28	-1.43	-0.09	-3.56
	1975	+1.34	-0.49	+0.71	-0.13	-1.33	+1.02	+1.12
IV, VII,	1979	+0.48	-0.48	-0.08	+2.96	-1.99	-1.06	-0.17
VIII, and IX	1980	-0.32	+0.26	+0.94	+1.29	+0.10	+1.50	+3.77
	1981	-0.40	-0.23	+0.29	+2.14	+0.91	-1.29	+1.42
	1982	0.00	-0.12	-0.68	+0.99	-1.53	+1.09	-0.25
	1983	-0.23	-0.62	-0.40	-1.10	+2.27	-0.29	-0.37
	1984	+0.17	+0.10	+0.19	+0.26	+0.08	-0.50	+0.30
	Normal	0.63	0.74	1.59	2.50	2.38	2.33	

Iceland, and Bottnia II from Sweden showed no evidence of winter injury. All other cultivars were intermediate in winter survival between those extremes, ranging from 50% (Drummond from Canada) to 88% (Tammisto from Finland). The two non-timothy

grasses, Polar bromegrass and Garrison creeping fox-tail, were rated at 100% winter survival.

Markedly poorer winter survival occurred with all timothy cultivars from Finland, Sweden, Canada, and the U.S. where plots had been swept bare of snow (Table



*Figure 6. Comparative winter survival of timothy cultivars in Exp. III. (Upper photo): Winterhardy plot on left is subarctic-adapted Korpa from Iceland; extensively winterkilled plot on right is mid-temperate-adapted Climax from Canada. (Lower photo): Severely winter-injured plot on left is Milton from Canada; uninjured plot on right is Bodin from northern Norway. Numbers on stake in center of each plot indicate height in feet. Plots planted 17 June 1974; photos taken 5 June 1975.*

3, Fig. 6). All six U.S. cultivars, all three from Canada, and two of the three from Sweden were estimated at less than 25% survival.

The three cultivars from Norway, and Korpa from Iceland, showed the best winter survival, averaging 93% (Fig. 6). Tammisto (65%) from Finland and Bottnia II (60%) from Sweden were intermediate in survival between the other entries, similar to their ranking in Exp. II. Polar bromegrass and Garrison creeping foxtail, grasses with predominately subterranean overwintering tissues, showed essentially no evidence of winter injury where snow cover was absent.

First-cutting forage yields in 1975 were strongly influenced by the above-described winter injury (Table 3). The nine cultivars from Canada and the U.S. had sustained the greatest winter injury and averaged only 0.40 T/A. In contrast, the four little-injured cultivars from Norway and Iceland averaged 1.94 T/A.

Most of the winter-injured timothy cultivars, however, showed a remarkable ability to recover during the growing season. As a result, most produced second-cut yields in mid-September equivalent to the more winterhardy cultivars and the two non-timothy grasses. Owing to generally good second-cutting yields, only three of the less winterhardy timothy cultivars from Canada and the U.S. were significantly lower in total two-cut yields than the most winterhardy cultivars from Norway, Iceland, and Finland; they were Lilly's Best, Clair, and Essex.

During autumn of 1975, an unusual temperature pattern, reported in detail elsewhere (Klebesadel 1977), resulted in total winterkill of all 17 timothy cultivars (Fig. 7). An atypically warm period during the first two-thirds of October undoubtedly slowed the development of freeze tolerance. This was followed in late October/early November by a precipitous temperature drop to near -10°F, and much-below-normal temperatures until mid-November. The following spring, Polar bromegrass and Garrison creeping foxtail, both with subterranean and therefore protected overwintering tissues, showed good winter survival. However, with all timothy cultivars dead, the experiment was terminated.

## Experiment IV

### Forage Yields and Winter Survival of 23 Timothy Strains in Broadcast-Seeded Plots

All entries in this experiment established well and, although it was planted late (11 July), July rainfall was almost three inches above normal (Table 5) and good forage yields were harvested in the seeding year 12 weeks after planting (Table 4). Eighteen of the 23 timothy cultivars produced over 1 T/A; in contrast, the four non-timothy grasses averaged only 0.77 T/A.

The winters of 1979-80 and 1980-81 were relatively mild; however, some winter injury of certain of the more southern-adapted timothy cultivars was apparent each spring. The winter of 1981-82 was somewhat more



Figure 7. Photo showing complete winterkill of all plots of 17 timothy cultivars from northern Europe and North America after second winter in Exp. III. Uninjured plots are Polar bromegrass and Garrison creeping foxtail. Randomly occurring individual living plants are Kentucky bluegrass. All three of the surviving grass species have less-exposed overwintering tissues than timothy. All plots planted 17 June 1974; photo taken 20 May 1976.

stressful than the previous two, causing more winter injury to timothies than the earlier two winters. Visual estimates of winter survival recorded on 22 June, and first-cut yields shortly afterward on 30 June 1982 (Table 4), showed the same association with latitudinal origin as was apparent in Exps. II and III. Mean first-cut yields for the northernmost-adapted and therefore most winterhardy cultivars from Norway and Iceland were always highest in 1980, 1981, and 1982. Progressively lower mean first-cut yields in all three years were obtained from strains from other countries in the order: Finland > Sweden > Canada > United States.

Considerable ranges were noted in comparative winterhardiness among cultivars from certain countries. From Sweden, Bottnia II was the most winterhardy and productive in first cuttings, while Omnia was least hardy and lowest yielding, a comparison consistent with results in Exps. II and III (Tables 2, 3). From Canada, Champ and Milton were best and Drummond poorest, and from the U.S., Itasca, a cultivar from Minnesota, an area of stressful continental-type winters was best, and Clair, from the more southern Indiana-Kentucky area of relatively mild winter stresses was poorest.

Mean forage yields for the 23 timothy cultivars were slightly higher in 1981 than in 1980; precipitation amounts were generally above average in both years (Table 5). Although the timothies generally surpassed the four non-timothy cultivars in seeding-year yields in 1979, the timothies and other species were about equal in total yields in 1980 and 1981.

### Other Corroboratory Studies

Another study at this location (Exp. II in Klebesadel 1993c) that compared 14 species of grasses for winterhardiness and forage yields for four years included Norwegian timothy cultivars Engmo, Bodin, and Va-BL-60. Those cultivars were among the most winterhardy and productive of forage, results that are consistent with findings in Exps. III and IV of this report.

Performance of timothy cultivars in Exps. I, II, III, and IV, showing a relationship between winterhardiness and latitude-of-origin, parallel those of Andersen (1960) and Østgard (1959) in northern Norway who reported that Engmo and Bodin, both originating in northern Norway, excelled in winter survival there. They found poorer winter survival in all other timothy cultivars compared in several tests, including strains from more southern sources in Norway, and from Sweden, Finland, Scotland, Canada, and the U.S. Korpa from Iceland and Va-BL-60 from Norway, cultivars that performed well in experiments reported here, were not included in their tests.

The present results agree generally with a report by

Mitchell (1989) wherein seven timothy cultivars were compared in a 2-year test near Delta Junction in interior Alaska. The most winterhardy and top yielders were Engmo from Norway, Tiiti from Finland, and Korpa and Adda from Iceland. Bottnia II was so injured during the last winter that no first-cutting was obtained; the cultivar Kampe from Sweden winterkilled totally during that winter, producing forage only during one year. Climax from Canada winterkilled the first winter.

Engmo and Adda survived winters well in another study of several grass species and cultivars at this location (Klebesadel and Dofing 1991).

Seven timothy cultivars (Engmo, Bodin, Korpa, Adda, Bottnia II, Kampe II, and Climax) were included in another test of 29 grass strains within 14 species conducted over three years at this location (Exp. IV in Klebesadel 1993c). The seven cultivars averaged 2.45 T/A in the seeding year, a year of above-average precipitation. However, due to below-normal precipitation during both subsequent years, especially during the first half of both growing seasons, first-cut yields of all timothies were low; thus, of the 29 grass strains, the seven timothy cultivars ranked from 7th to 18th in total yields for the three years. Both winters during the experiment were relatively mild. Because winter injury was very minor, Climax, a relatively nonhardy cultivar here, ranked above the other much more winterhardy timothy cultivars in 3-year total yield.

### Seasonal Distribution of Yields

When forages are harvested twice per year, the date of the first harvest governs the duration of the periods of growth allotted for both the initial growth prior to the first cutting, and for the regrowth that develops between the first and second cuttings. Thus, in the absence of appreciable winter injury, the date of the first cutting imposes a major influence on the amounts of dry-matter produced in the first versus the second cutting. Abundance or shortage of soil moisture, however, also can markedly promote or limit growth in either half of the growing season and thus influence yields.

Additionally, though, with relatively similar first-cut harvest dates in both years of Exp. IV, an interesting comparison can be seen in the distribution of yields in the first and second harvests as it relates to the latitude-of-origin of the cultivars. The pattern was generally similar in both years; for the nine most winterhardy cultivars (from Norway, Iceland, and Finland), two-year means of the proportion of total forage yield in the first cutting was consistently highest at 57%. The percentage was progressively lower for less winterhardy groups (Sweden = 44%), and especially for increasingly more southern-adapted groups (Canada = 39%, and U.S. = 36%).

In Exp. II, where the winter of 1974–75 inflicted greater winter injury, the eight cultivars from Norway, Iceland, Finland and Sweden averaged 34% of the total-year yield in the first cutting of 1975 while the Canadian cultivars averaged 17% and those from the U.S. only 11%.

To a considerable extent, the above differences in yield distribution in first cutting were due to the inability of winter-injured strains to put forth growth at full normal capacity as those plants gradually recovered prior to the first cutting. Moreover, the weak and recovering winter-injured grasses understandably were unable to fully utilize the relatively high rate of spring-topdressed fertilizer prior to the first cutting. Therefore, a more abundant supply of nutrients (and probably soil moisture) would be available during the regrowth of those cultivars than in the case of the more winterhardy, non-injured cultivars which drew more heavily on fertilizer and soil moisture to produce high first-cut yields.

In addition, however, cultivar differences in growth habit, that are related to latitude-of-adaptation and winterhardiness, contribute also to the aforementioned differences in yield distribution in the two harvests. Engmo and Korpa, the two northernmost-adapted cultivars in Exp. IV, averaged only 37% of total-year yields in the second cutting; that regrowth consisted virtually entirely of basal leaves with very few extended culms. In contrast, all timothy cultivars from Canadian and U.S. origins produced heavy crops of head-bearing culms in their regrowths, with resultant high forage yields in the second cutting (Table 4). Several cultivars of intermediate winterhardiness, and originating from intermediate latitudinal areas in

Scandinavia, exhibited growth characteristics in the regrowth intermediate between the above extremes.

### Autumn Dormancy

About one week after the second cutting in 1981, harvested on 17 September, the various timothy cultivars exhibited different amounts of new leaf growth. All plots were rated for height of new regrowth (Table 4, Fig. 8). The ratings were found to parallel generally the relative winterhardiness of cultivars, with the least winterhardy exhibiting most autumn regrowth, and the most winterhardy producing virtually none.

That regrowth, and absence of same, may be indicative of different extents of dormancy assumed by the strains. Lack of regrowth after the mid-September harvest suggests onset of a dormant condition assumed by northern-adapted cultivars, perhaps an acquired and appropriate response to accustomed environmental changes at that time of year (probably photoperiod) at subarctic latitudes. The greater amounts of regrowth by the more southern-adapted cultivars suggest that they were not induced to assume a similar state of dormancy; that failure could indicate poor harmony with northern environmental cues that probably deters their adequate preparation for winter and increases their susceptibility to winter stresses.

In Norway, Håbjørg (1979) observed that late-season growth was associated with poor winter survival in mid-temperate-adapted Kentucky bluegrass cultivars when they were grown at 70°N. Cultivars adapted at that subarctic latitude ceased vegetative growth earlier in autumn and were markedly superior in winter survival there.



Figure 8. Individual timothy plants of two subarctic-adapted cultivars (Engmo and Korpa) and two mid-temperate-adapted cultivars (Climax and Clair) showing different amounts of regrowth following the second forage harvest on 17 September 1981 in Exp. IV; photo taken 3 November. The more dormant Engmo and Korpa are vastly more winterhardy than Climax and Clair that exhibited considerably more late-season growth.

## Experiment V

### Pre-winter Dry-Matter Concentration and Food-Reserve Storage in Overwintering Tissues of Cultivars Adapted at Diverse Latitudes

Three timothy cultivars, representing widely separated latitudes of adaptation (Fig. 9), were selected for comparisons in Exps. V and VI to compare, when grown in this subarctic location, various characteristics as they relate to winterhardiness. Engmo, described earlier, derived from 69° to 70°N in northern Norway. Climax was selected near 45°N at Ottawa, Ontario, and Clair, representing 38° to 39°N, originated from a naturalized strain in southern Indiana and was increased and released at Lexington, Kentucky (Hanson 1972).

Those cultivars therefore represent selection within the species for adaptation at three widely separated latitudes over a north-south range of over 2,000 miles and 32 degrees of latitude. Those three origins represent marked differences in climate, growing seasons, winter stresses, and seasonal photoperiodic patterns. The latitude of the Matanuska Research Farm (61.6°N), where these tests were conducted, is intermediate between the origins of Climax and Engmo, but closer to the latter.

### Dry-Matter Concentration in Overwintering Crown Tissues

The crown of the timothy plant is positioned at the soil surface and consists of a cluster of culm and tiller bases below which the roots descend (Figs. 4,8). The crowns represent the primary overwintering tissues of the plant and those tissues undergo metabolic changes during late summer and autumn that permit successful winter survival. One of those changes is an increase in the bound water of the plant's protoplasm but, coincident with that increase, a decrease in the total water in overwintering tissues (Smith 1964a).

In this experiment, dry-matter concentration increased rapidly in plant crowns of all three cultivars from the first sampling on 22 August to the final sampling near the time of soil freeze-up on 10 October (Fig. 10). The cultivars were essentially identical in percent dry matter in tissues on 22 August. Moreover, during the subsequent increase, differences between Climax and Clair were not significant on either of the following sampling dates.

Crowns of Engmo increased more rapidly in percent dry matter than Climax and Clair, the difference between Engmo and the other two increasing with each sampling. Percent dry matter in Engmo crowns doubled in the 49 days between the initial and final sampling, and was significantly higher than in Climax and Clair at the second and third samplings.

A close relationship was found by others (Metcalf *et al.* 1970) between percent dry matter in the plant crowns of winter wheat (*Triticum aestivum* L.) and barley and injury from freezing at different temperatures. Greatest extent of injury occurred with high crown-moisture content (low percent dry matter). Moreover, they reported that a small change in percent dry matter in crowns at a given freezing temperature resulted in a very large difference in plant survival.

In the larger study (Klebesadel 1993d) from which these timothy results were drawn, a similar pattern was found within several other species of (a) high percent dry matter in overwintering tissues of subarctic-adapted ecotypes associated with superior winter survival, versus (b) lower percent dry matter in more southern-adapted ecotypes that was associated with poorer winter survival. Species within which that pattern was found included Kentucky bluegrass, red fescue, slender wheatgrass, alfalfa (*Medicago sativa* L.), and biennial white sweetclover (*Melilotus alba* Desr.).

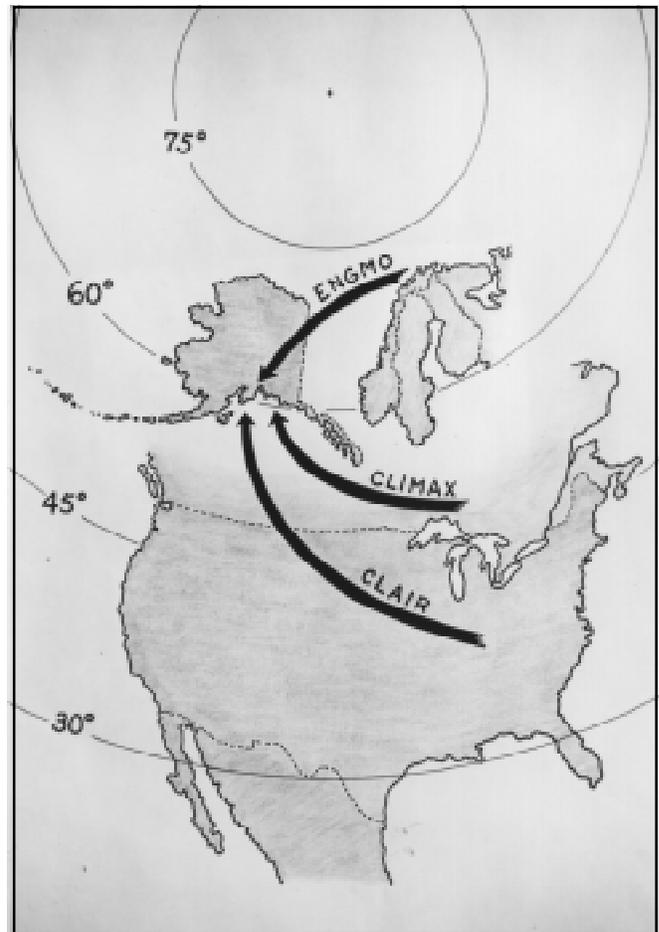


Figure 9. Map with Alaska and Scandinavian Peninsula re-positioned over the conterminous U.S. to show latitudinal relationship of origins of timothy cultivars used in Exps. V and VI.

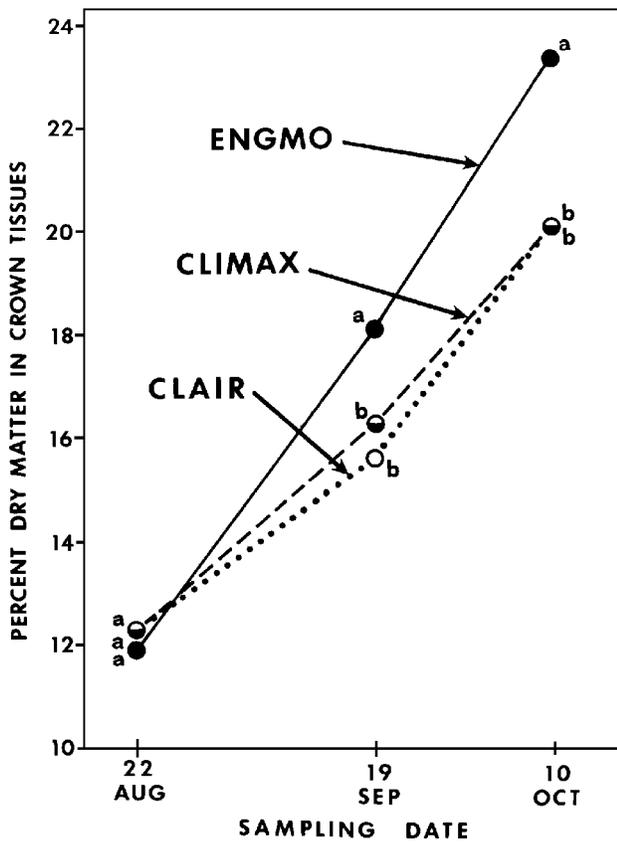


Figure 10. Changes in percent dry matter during winter-hardening period in overwintering crown tissues of three timothy cultivars of diverse latitudinal adaptation (Exp. V). Values on each date not accompanied by a common letter differ significantly (5% level).

The row plantings in the field, from which these timothy crowns were taken, showed great differences in winter survival. Plants of Engmo survived well in both years, averaging 95%. In contrast, Climax and Clair, whose crowns had significantly lower pre-winter percents dry matter, survived the first winter at 4% and 2%, respectively, and both winterkilled completely during the second winter. Those relative percents winter survival of Engmo, Climax, and Clair are consistent with survival differences of the same cultivars in other studies at this location (Klebesadel 1970, 1992a).

### Storage of Food Reserves in Late-Summer/Autumn

The manufacture of carbohydrate food reserves through photosynthesis, and increased storage of those reserves in overwintering tissues is another process occurring during the time of increase in dry-matter concentration (decrease in total water content) in those tissues during late summer and autumn. Those stored reserves provide the energy plants use in developing winterhardiness, in

living over winter, and for initiating new growth during the following spring (Smith 1964b).

None of the three cultivars showed evidence of stored reserves (as measured by etiolated growth from plant crowns) when removed from the field on 10 August (Exp. Va). All three cultivars, however, did express stored reserves after sampling on 22 August (Exp. Vb); Engmo Climax, and Clair produced respectively 131, 53, and 47 oven-dry milligrams of etiolated growth per gram of oven-dry crown tissues potted. The much higher value for Engmo suggests that this far-northern-adapted cultivar is much better attuned to initiating early storage of food reserves under Alaska conditions (logically a photoperiod/nyctoperiod response) than the more southern-adapted Climax and Clair. Those cultivars are accustomed to a longer pre-winter growth period of shorter photoperiods/longer nyctoperiods for adequate food-reserve storage in their areas of adaptation. All three cultivars possessed higher levels at the final sampling

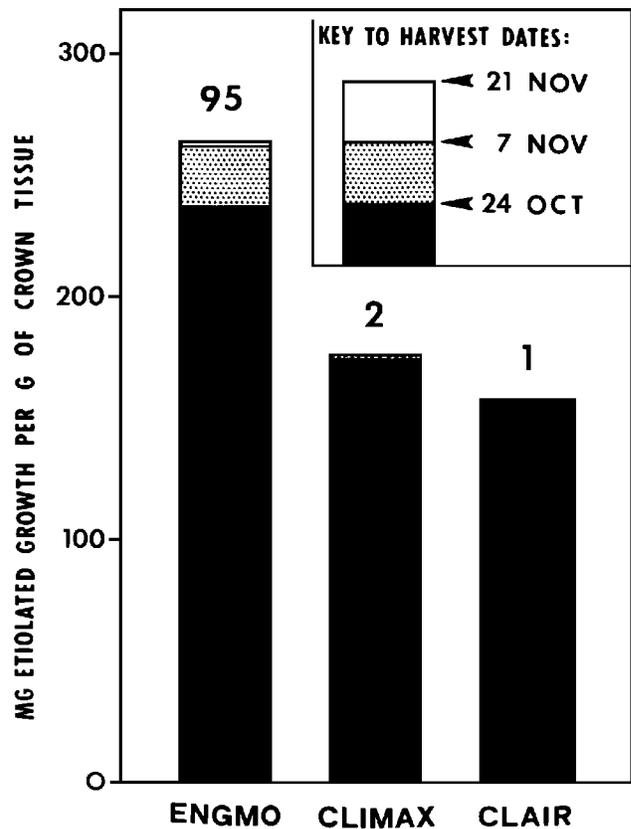


Figure 11. Two-year means (Exps. Va and Vb) of stored food reserves as measured by etiolated growth harvested at 2-week intervals from crowns of three timothy cultivars of diverse latitudinal adaptation. Plants removed from field on 10 October both years, 111 days after planting; all weights on oven-dry basis. Numbers above bars are 2-year means of percent winter survival of individual, spaced plants in rows of each cultivar that remained in the field over winter.

in both experiments on 10 October (Fig. 11). Engmo showed a considerably greater amount than the other cultivars following the October sampling as well; Climax was slightly superior to Clair at the final sampling.

At the 10 October sampling, three bi-weekly growth periods in darkness were required to totally exhaust stored reserves in Engmo, only two growth periods for Climax, and Clair crowns produced no etiolated growth after the first 2-week growth period.

Smith (1964b) stated that plants with low levels of stored reserves cannot develop a high level of winterhardiness. Whether the lower levels of reserves measured in Climax and Clair were adequate or not to permit maximum hardiness development is not known. However, the relative levels of stored reserves measured in the three cultivars did parallel their percent winter survival in the field (Fig. 11).

It was apparent that the far-northern-adapted Engmo responded more vigorously in early storage of food reserves under Alaska's conditions than the much more southern-adapted Climax and Clair. Engmo probably is genetically attuned to initiating rapid storage of food reserves under longer photoperiods than Climax and Clair. The latter two probably would have stored higher levels of food reserves with a longer growing period of

short photoperiods before killing frost. It is known that mid-temperate-adapted grasses can survive Alaska winters better if provided artificially with a longer pre-winter growing period of short photoperiods/long nyctoperiods than occurs naturally in Alaska (Klebesadel 1971, 1985b).

## Experiment VI

### Freeze Tolerance During the Cold-Hardening Period of Cultivars Adapted at Diverse Latitudes

The bulb-like corms at the stem bases of timothy represent the principal storage organs for food reserves and are the sites of new tiller growth (Figs. 4, 12) and, as discussed earlier, they are also important overwintering tissues critical to winter survival and continual growth and productivity of plants. Figure 12 shows the progression of corm preparation for the freeze-tolerance test, from whole plant to trimmed corms as done on 30 October.

Engmo corms were significantly less injured by freezing at all three temperatures than those of the more southern-adapted and less winterhardy Climax and Clair (Fig. 13). Furthermore, Engmo was more injured at  $-36^{\circ}\text{C}$  than at  $-24^{\circ}\text{C}$ , indicating that  $-24^{\circ}\text{C}$  did not cause as much freeze injury as the colder temperature. This contrasted

with Climax and Clair, both of which were essentially as much injured at  $-24^{\circ}\text{C}$  as at  $-36^{\circ}\text{C}$ , and differed very little in injury at either of those temperatures. In fact, Climax and Clair did not differ significantly in extent of corm-tissue injury at any of the three temperatures although, when frozen at  $-12^{\circ}\text{C}$ , the more southern-adapted Clair sustained somewhat greater injury than Climax. Thus, the  $-12^{\circ}\text{C}$  freeze stress served to cause slight differences in freezing injury between Climax and Clair that parallel their actual relative winter survival in the field (Exps. III, IV, V).

The ranking of Engmo, Climax, and Clair in the artificial freeze-tolerance test, and the relationship



Figure 12. (Left) The total crown growth of a timothy plant; (Center) two stem bases separated from the crown cluster showing new tiller growth arising from the base of the corms; old sheath growth on stem base at right has been peeled away to better expose corm; (Right) three corms trimmed of tillers and roots showing overwintering storage tissue utilized in freeze-tolerance test (Exp. VI). Ruler length is 10 centimeters (4 inches).

of those results to winter survival in the field and to latitude of origin, parallels results reported earlier for bromegrass at this location (Klebesadel 1993a). In that study, the ranking of four bromegrasses in an artificial test of tolerance to freeze stress also matched their relative winter survival in field experiments and was associated as well with their latitude of adaptation. The similar sets of results in the bromegrass study and in the present test with timothy indicates that a high tolerance to freeze stress is an important factor in winter survival in the field.

In another test of freeze tolerance of timothy cultivars involving a lesser latitudinal range but with generally similar results, Andersen (1960) in northern Norway froze outdoor-hardened plants at  $-10^{\circ}\text{C}$  for 48 hours in September and early October, then counted surviving plants three weeks later. He found Engmo and Bodin from northern Norway to be more tolerant of freeze stress than Bottnia II from a lower latitudinal origin in Sweden, a ranking that matches the relative winter injury of those strains in Exp. III of the present report (Table 3). Andersen reported that poorest survival occurred with Grinstad, a cultivar from southern Norway; that cultivar also exhibited somewhat poorer winter survival than Engmo, Bodin, and Bottnia II in Alaska in Exp. I (Table 1).

## Experiment VII

### Effects of Planting Dates and Seeding-Year Harvest Dates on Seeding-Year Forage Yields and on Subsequent Winter Survival and Spring Forage Yield

Oven-dry seeding-year forage yields of Engmo timothy, harvested on six dates at approximately 10-day intervals from 22 August to 9 October, averaged 2.30, 1.88, and 0.69 T/A from stands seeded 16 May, 1 June, and 19 June, respectively (Fig. 14). Forage yields obtained on the different harvest dates from the 16 May planting were somewhat erratic, followed no clear pattern, and all were 2.0 T/A (22 Aug. harvest) or more. Seeding-year yields from the 1 June planting followed a clearer pattern of increasing from first-to-last harvest (1.42 to 2.09 T/A) as the stand aged with successive harvests. Yields from the latest (19 June) planting also increased from first-to-last harvest and, although yields were much lower than from the earlier plantings, the increase from first harvest (0.24 T/A) to last (1.02 T/A) was greater.

The different effects of the 1980 seeding-year harvests on plots seeded 19 June were very apparent in spring of 1981 (Fig. 15); it was quite obvious that the

later harvest dates resulted in winter injury. It is probable that the successively later harvests removed leafy aerial growth from plants at a time it was needed by plants to make optimum preparation for winter (Halling 1988).

The different seeding dates in 1980 influenced first-cut forage yields in 1981 to some extent (Fig. 14); mean yields (over all seeding-year harvest dates) for plots planted 16 May, 1 June, and 19 June were 2.08, 1.62, and 1.32 T/A, respectively.

The influence of seeding-year harvest dates tended to be similar within each planting date; with successively later harvest dates in 1980, first-cut forage yields in 1981 tended to be progressively lower. That effect was greater in plots planted 19 June than with earlier planting dates (Fig. 14). With plots planted 19 June, seeding-year harvests on 22 August, and 2, 11, and 23 September resulted in a precipitous drop in 1981 first-cut yields from 2.28 to 0.86 T/A; later harvests (1 and 9 Oct.) resulted in low yields also (0.93 and 0.86 T/A).

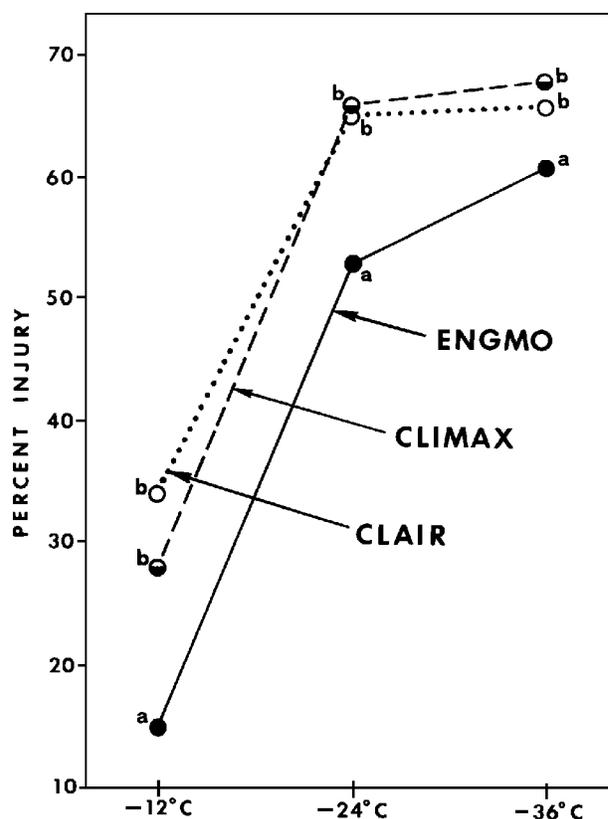


Figure 13. Percent injury in overwintering crown tissues of three timothy cultivars of diverse latitudinal adaptation when frozen for 20 hours at three temperatures (Exp. VI). Test conducted in late October after termination of the growing season and just prior to soil freeze-up on plants that were seeded 9 May. At each temperature, means not accompanied by a common letter differ significantly (5% level).

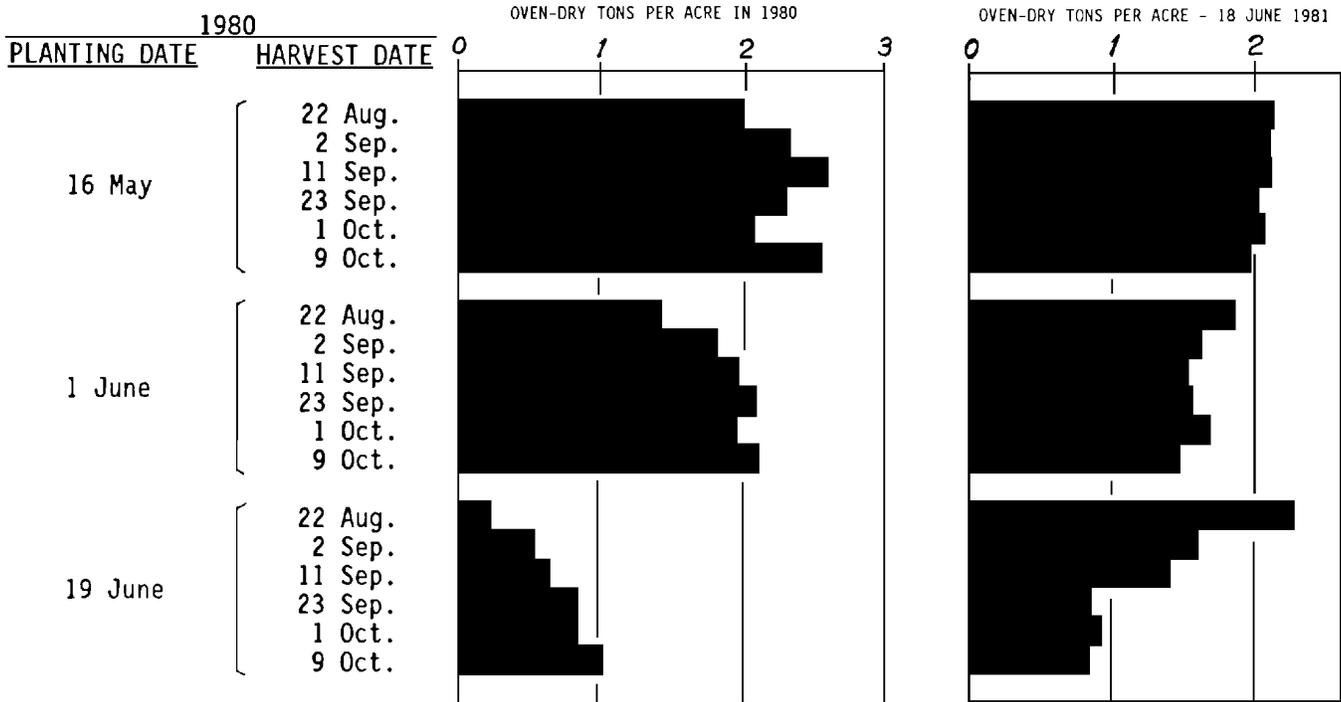


Figure 14. (Left) Seeding-year forage yields of *Engmo timothy* planted on three dates in 1980 with plots within each planting date harvested on six different dates. (Right) First-cut forage yields on 18 June 1981 as influenced by the different planting and seeding-year harvest dates in 1980 (Exp. VII).

Other studies at this location have found that other grasses seeded in mid-June also were predisposed to winter injury and lowered first-cut yields the following year when seeding-year harvests were taken on certain inappropriate dates. Manchar smooth brome grass and Polar brome grass were winter-injured most after seeding-year harvests were taken on 10 September and 31 August, respectively (Klebesadel 1993b). Siberian wildrye responded quite similarly to Manchar brome grass; it sustained greatest winter injury after seeding-

year harvest near mid-September (Klebesadel 1993c).

Unlike timothy, however, those grasses fared progressively better when seeding-year harvests had been increasingly earlier or later than the most harmful dates. Although Exp. VII represents results from only one test, and more similar experiments should be conducted, all of the three latest harvests (23 Sep., 1 and 9 Oct.) were equally harmful with mid-June-planted timothy (Fig. 14).



Figure 15. Overall view of block of *Engmo timothy* plots in Exp. VII seeded 19 June 1980 and photographed 13 May 1981. Differences in winter injury and spring growth are due to different dates of seeding-year forage harvest. Closest plots were harvested (left to right) 23 Sep., 1 Oct., 22 Aug., 2 Sep., 11 Sep., and 9 Oct.

## Experiments VIII and IX

### Effects of a Broad Array of Harvest Schedules and Frequencies on Forage Production and on Subsequent Winter Survival of Established Timothy Forage Yields in Year of Differential Harvests

Although Experiments VIII and IX were generally similar in design, the latter had six more treatments and the results of the two experiments were quite different, both in the year of differential harvests and in the uniform evaluation harvest of the final year.

The four different first-cutting dates were roughly similar in both experiments: 2, 10, 22, and 30 June in Exp. VIII, and 8, 13, 20 June and 1 July in Exp. IX. Each later date of first-cut harvest resulted in progressively increasing yields. However, mean first-cutting yields in the two experiments differed markedly; although most first-cut dates were slightly later in Exp. IX, yields were much lower. Mean oven-dry yields for the four first-cut harvests in Exp. VIII were 1.38, 1.98, 2.89, and 3.39 T/A (Fig. 16), while in Exp. IX they were only 0.27, 0.63, 1.45, and 2.76 T/A (Fig. 17).

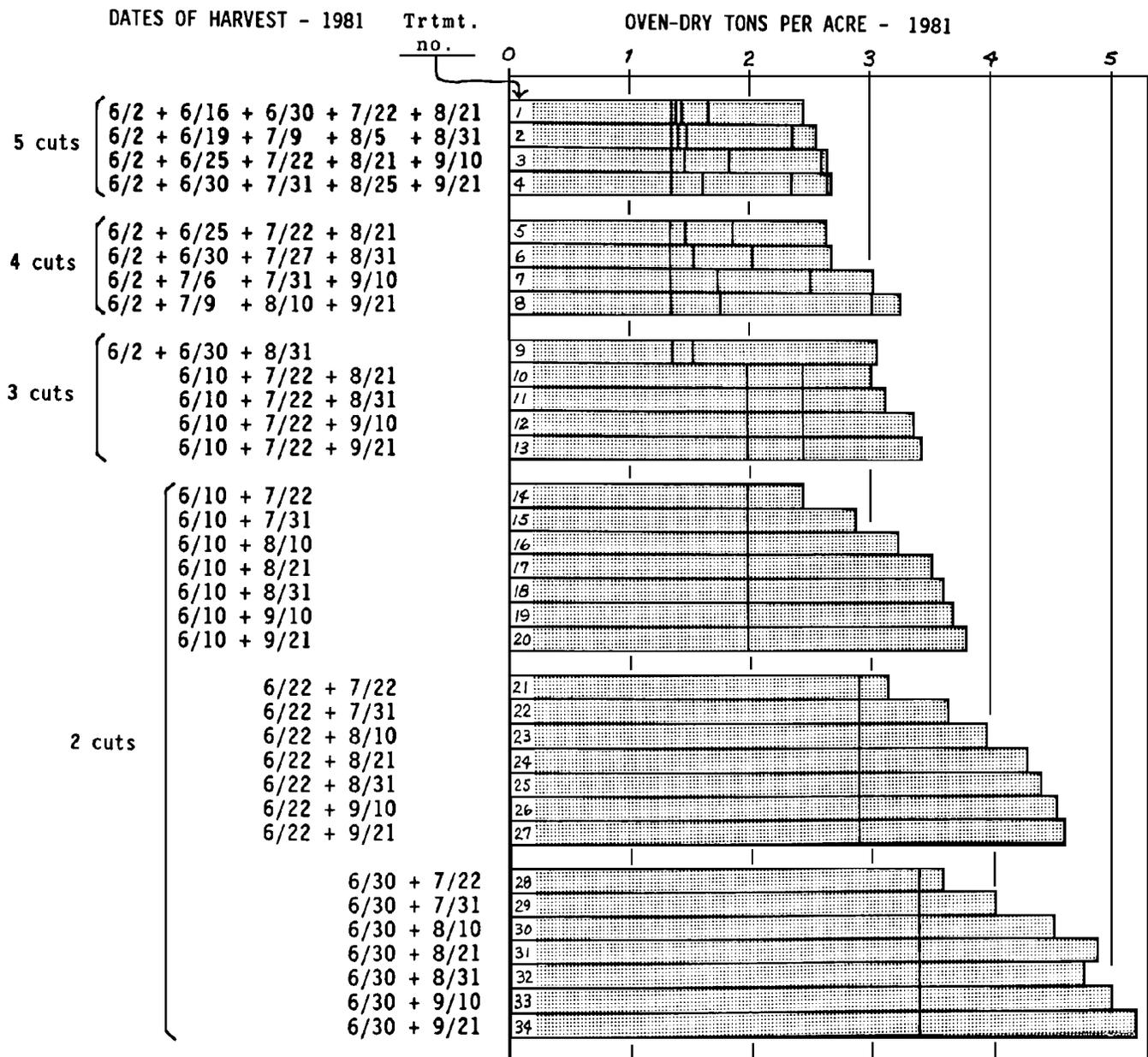


Figure 16. Forage yields of *Engmo timothy* in Exp. VIII as influenced by 34 harvest treatments (different schedules and frequencies of harvest). Vertical lines within bars indicate yields obtained in successive harvests. Mean yields are shown where a group of several first or second cuttings were harvested on the same date. Treatment number appears in left end of each graph bar.

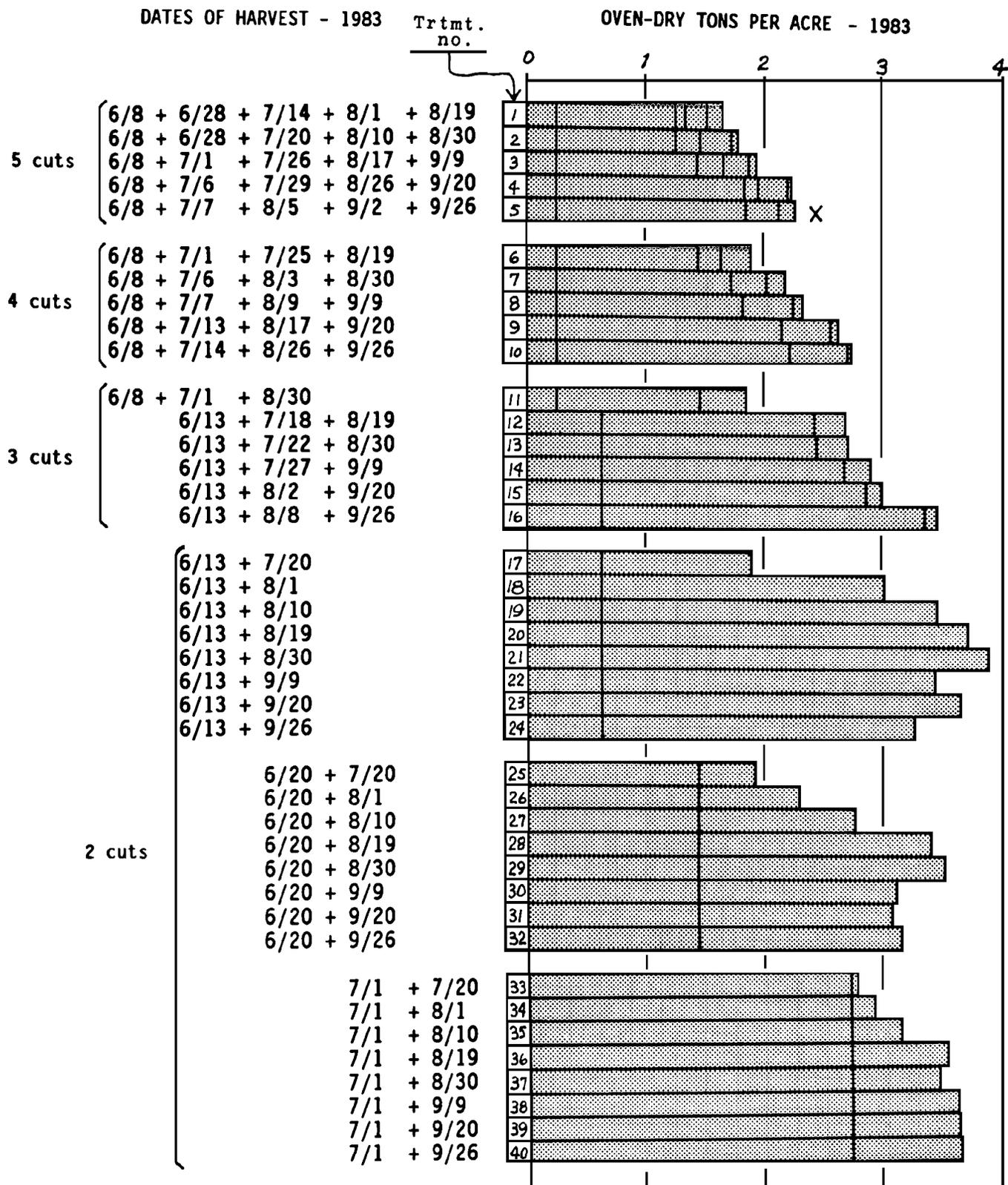


Figure 17. Forage yields of *Engmo timothy* in Exp. IX as influenced by 40 harvest treatments (different schedules and frequencies of harvest). Vertical lines within bars indicate yields obtained in successive harvests. Mean yields are shown where a group of first cuttings were harvested on the same date. The symbol (x) at the end of bar for treatment 5 indicates intended fifth harvest on 26 September, but regrowth was inadequate for a harvestable yield. Treatment number appears at left end of each graph bar.

The considerable difference in yields between the two experiments apparently was due primarily to differences in precipitation received both in the year of these harvests but also during the latter portion of the prior growing season (Table 5). Although the relatively shallow silt mantle (generally 18 to 24 inches at the experimental sites) over coarse sand and gravel represents a modest reservoir for storage of soil moisture, it can nonetheless be extremely important to spring growth of forages. If the soil is well supplied with precipitation during the latter part of the previous growing season, the carry-over supply of soil moisture can compensate considerably for the very modest rainfall normally received in April, May, and June. This is especially important because the generally meager precipitation received during the first months of the growing season (Table 5) can be inadequate for meeting the growth requirements and realizing the full potential for herbage dry-matter production of a moisture-sensitive perennial forage grass such as timothy.

Although total precipitation for April, May, and June of 1981, the year of high first-cut yields in Exp. VIII (Fig. 16), was 0.34 inches below normal, total precipitation for August and September of the previous year (1980) was 1.60 inches above normal, apparently sufficient for building a high soil-moisture content for spring growth in 1981.

In contrast, the much lower first-cut yields in Exp. IX in spring of 1983 apparently were attributable largely to 0.44-inch below-normal precipitation in August and September of 1982 followed by 1.25 inches below-normal precipitation in April, May, and June of 1983. These results agree with earlier reports attesting to poor productivity of timothy under low soil-moisture conditions (Hanson 1972; Lambda *et al.* 1949; McElroy and Kunelius 1995; Smith *et al.* 1986).

Another marked difference between the two experiments was the unequal distribution of yields between first and second cuttings (Figs. 16, 17) in all treatments where a first cutting was taken in early June (2 June in Exp. VIII, 8 June in Exp. IX). Those differences are believed due to dissimilar stages of grass development and therefore height above the soil of the hidden growing points (shoot apices) within the culms on the first-cutting dates (Fig. 18).

The slow-starting, short, moisture-stressed, and low-yielding (Fig. 17) spring growth of the grass harvested 8 June in Exp. IX probably had most of the growing points beneath the level of the sickle-cutting height, and those therefore were not removed with the herbage harvested. Thus they were able to continue growth and

contributed to high yields in all second cuttings harvested during late June and early July (trtmts. 1 through 11).

In contrast, although the earliest first cutting in Exp. VIII was six days earlier than in Exp. IX, that experiment was better supplied with soil moisture for spring growth in 1981 and produced much earlier and more robust growth and higher yields (Fig. 16); most of the growing points probably were removed in that first cutting on 2 June. The second-cuttings of treatments 1 through 9, harvested from mid-June to early July, were thus very low because regrowth had to develop from delayed elongation of secondary tillers on the plant crowns (Grant 1971; Grant and Burgess 1982; Sheard 1968).

Beyond differences in spring moisture supply in the two experiments, spring temperature differences likely contributed to different rates of spring growth also.

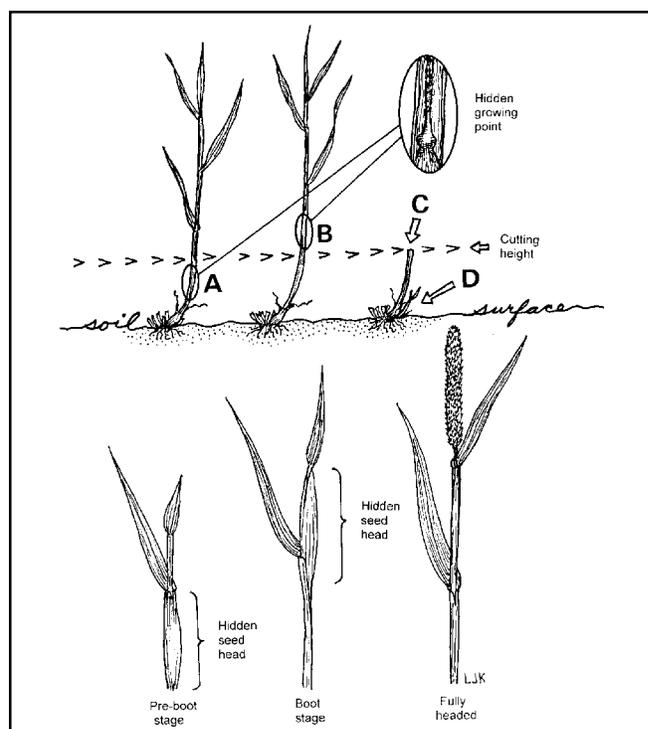


Figure 18. (Upper) A spring-growing tiller showing the importance of height of hidden growing points (shoot apices), in relation to cutting or grazing height, on continued growth of those tillers. If growing point is below the level where early growth is severed (as at A), tiller will continue to grow into a fully developed stem or culm. However, if growing point is above cutting height (as at B), growth of tiller stops (as at C) and new growth must arise from slowly developing basal tillers (D) that ordinarily would not begin active growth until after harvest of fully developed primary growth, usually in late June. (Lower) Terminology describing sequence of developmental stages in relation to elevation of the seed head hidden within the culm and its emergence to visibility. The term "boot" refers to the uppermost leaf sheath.

During May of 1981 (Exp. VIII) and May of 1983 (Exp. IX), respective average maximum temperatures were 63.4° and 58.7°F, average minima were 40.8° and 37.3°F, and average temperatures for the month were 52.1° and 48°F. Thus, lower temperatures as well as more limited soil moisture slowed spring growth in Exp. IX. Landstrom (1990) in northern Sweden studied in detail and reported on the influence of temperature on spring growth of timothy.

Additional information on spring growth differences in Exps. VIII and IX were development notes recorded during the experiments; on 10 June 1981 (Exp. VIII) unharvested grass was “beginning to head” while, on 13 June 1983 (Exp. IX), the considerably more retarded grass development was recorded as “ranging from pre-boot to late-boot stage, mostly early to mid-boot stage” (Fig. 18).

This pattern of very slow regrowth when growing points are removed by early cuttings in early June is well known and documented for smooth brome grass (Klebesadel 1992b, 1994a; Smith and Nelson 1985; Smith *et al.* 1986).

### Rates of Primary Growth

The four progressively later dates of first cuttings of many plots in both experiments permitted the calculation of rates of herbage production in previously unharvested primary growth of Engmo during the month of June; those rates, expressed as pounds of oven-dry herbage produced per acre per day were:

Exp. VIII (1981)		Exp. IX (1983)	
Growth interval	Growth rate (lb/A/day)	Growth interval	Growth rate (lb/A/day)
2 to 10 June	152	8 to 13 June	146
10 to 22 June	151	13 to 20 June	233
22 to 30 June	125	20 June to 1 July	238
Overall (6/2 to 6/30)	144	Overall (6/8 to 7/1)	178

The table shows rates of growth for three intervals among the four first cuttings, as well as an overall rate between the first and last first cuttings. Rates of growth were believed impeded somewhat by below-normal rainfall in both experiments (Table 5). Although yields generally were higher in Exp. VIII (Fig. 16) than in Exp. IX (Fig. 17), the rate of growth between first and last first cuttings was greater in Exp. IX than in Exp. VIII (178 vs. 144 lb/A/day).

Those values are considerably below some rates of growth reported for Polar brome grass with the same rate of spring fertilizer application at this location (Klebesadel

1997). However, the differences probably are due more to differences in moisture supply in the different years than to inherent productivity of the grasses; for an accurate comparison of maximum growth rates of these principal forage cultivars used in this area, both should be grown together in the same experiment and provided with abundant supplies of supplemental irrigation and fertilizer nutrients.

### Yields in Subsequent Harvests

Within each harvest frequency, total yields for the year generally increased as final harvests were taken on progressively later dates. This pattern was more consistent in Exp. VIII where late-season regrowth was better supplied with soil moisture. In that experiment, July + August precipitation was 3.05 inches above normal while, in Exp. IX, July + August precipitation was only 1.17 inches above normal. In Exp. IX (Fig. 17) the increase in yields of regrowth with later final harvests was apparent with 3-, 4-, and 5-cut frequencies but continued only up to about the 19 August harvest with the 2-cut treatments. In Exp. VIII, the better supply of precipitation resulted in increasing yields generally up to the latest harvests on 21 September (Fig. 16).

Among 2-cut treatments, total-year yields in Exp. VIII generally were progressively higher as first-cutting dates were later (Fig. 16). That pattern did not occur in Exp. IX (Fig. 17); in that experiment the total-year yields of the highest-yielding, 2-cut treatments were as high with the earliest first-cut date (13 June) as with the two later first-cut dates (20 June and 1 July).

The good herbage production of timothy throughout Alaska’s relatively cool growing seasons, as shown in these experiments, contrasts with the acknowledged poor productivity of this grass during hotter summers at more southern latitudes (Hanson 1972; McElroy and Kunelius 1995; Smith *et al.* 1986). Smith and Jewiss (1966) stated concerning timothy in the U.S. Midwest: “Little dry matter is produced during the warm summer period; most is produced during the cool spring and autumn periods.” With good winter survival and soil fertility, the sole deterrent to high season-long productivity of timothy in this relatively cool-summer area is limited soil moisture.

### Uniform Evaluation Harvests

The generally good winter survival of Engmo timothy in both Exps. VIII and IX differed markedly from some other experimental studies at this location when more stressful winters have caused considerable winter injury or total winterkill of this cultivar (Exp. III of this report; also Klebesadel 1992b, 1994b).

The uniform evaluation harvests of the two experiments did, however, differ in two ways, (a) the average amount of herbage produced, and (b) the effects of treatments on evaluation-harvest yields. The mean evaluation harvest yield of all 34 treatments in Exp. VIII (2.02 T/A) was less than half of the mean yield of the 40 treatments in Exp. IX (4.50 T/A). The uniform evaluation harvest in Exp. IX on 2 July 1984 was nine days later than the 23 June 1982 harvest in Exp. VIII and that difference

could have contributed to some of the difference in yields. However, the dominant contributor to the difference is believed to be the quite different amounts of precipitation received prior to those harvests (Table 5).

Precipitation for August and September of 1981 and April, May, and June of 1982 was 1.18 inches below normal, resulting in the low overall yields on 23 June 1982 in Exp. VIII. In contrast, precipitation for the same months in 1983 and 1984 was 2.44 inches above normal,

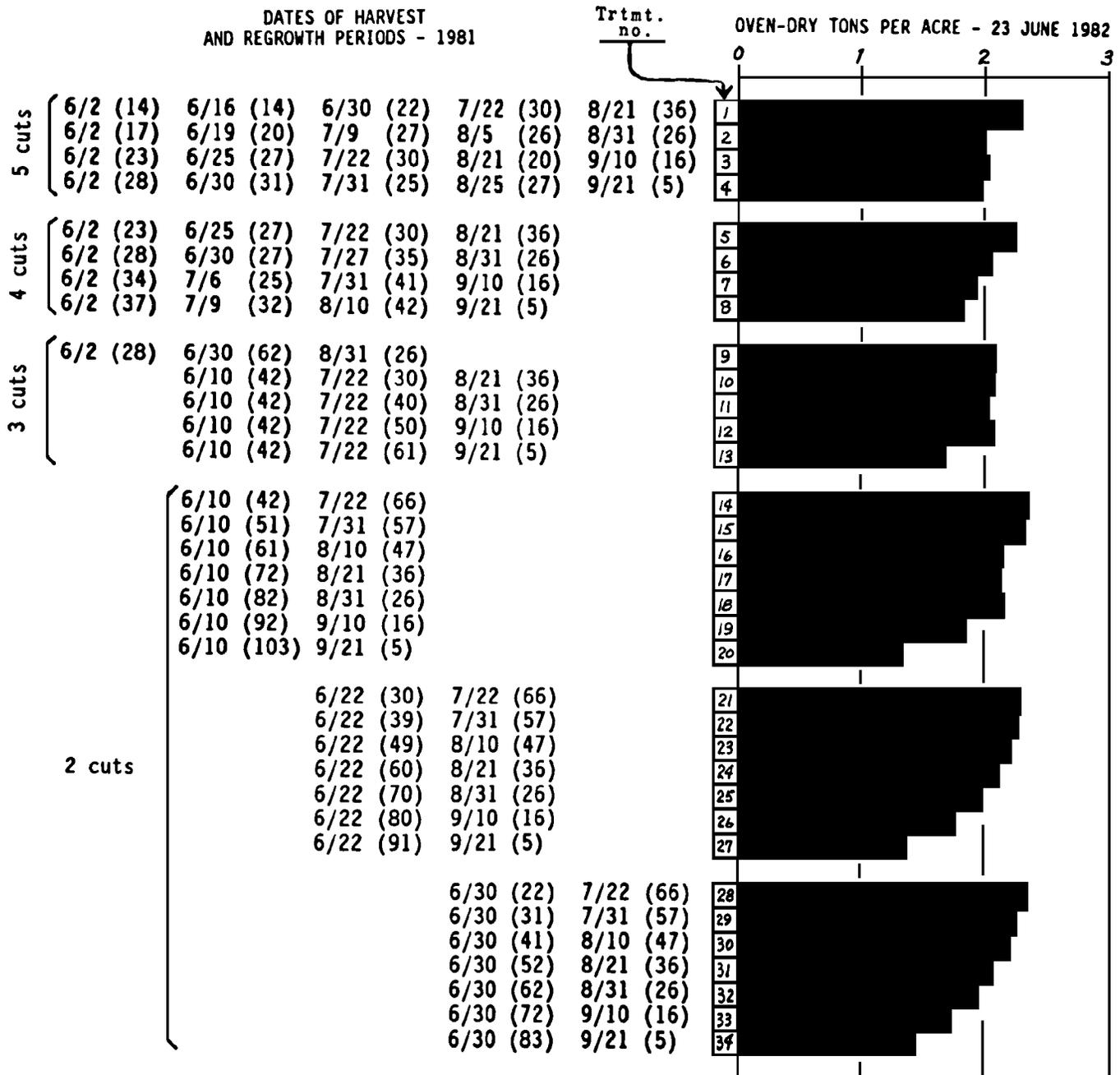


Figure 19. Forage yields of *Engmo timothy* in Exp. VIII in the uniform evaluation harvest on 23 June 1982 as influenced by 34 different schedules and frequencies of harvest during 1981 as shown in Figure 16. Numbers in parentheses between cuttings = number of days between cuttings; numbers in parentheses after final cuttings = number of days between final cutting and killing frost of 20°F on 26 September. Treatment number appears at left end of each graph bar.

thus the much higher yields in Exp. IX on 2 July 1984.

The other difference between the two experiments in uniform evaluation harvests was that no pattern of differences in yields as influenced by treatments was apparent in Exp. IX while, in Exp. VIII, a clear pattern of treatment effects was apparent (Fig. 19). It is believed that the lack of treatment-induced differences in the uniform evaluation harvest in Exp. IX, in contrast to Exp. VIII, is evidence of milder winter stresses during the 1983–84 winter (Exp. IX) than during the 1981–82 winter (Exp. VIII).

To a very minimal extent in the 4-cut and 3-cut treatments in Exp. VIII, but to a very marked extent in the 2-cut treatments, yields were lowest where final harvest had been on the latest date (21 Sep.) in the prior year (Fig. 19).

Moreover, within each of the three groups of 2-cut treatments (3 different first-cut dates), a clear pattern was apparent of highest yields with the earliest second-cutting date followed by lowering yields with progressively later final cutting dates. This pattern probably would have been more exaggerated if stresses during the prior winter had been greater.

It should be noted, however, that the 2-cut treatments with early second cuttings (that produced high yields in the evaluation harvest in Exp. VIII—Fig. 19) were not the highest yielding in the year of differential harvests (Fig. 16). This suggests that a compromise time of second cutting (if only 2 cuttings are taken) should be selected (probably 20 to 30 August), late enough to secure a good yield in the second cutting but early enough to ensure against negatively affecting stand health.

First cutting dates of treatments 14 through 34 had no effect on evaluation-harvest yields, for yields within each of the three groups of 2-cut treatments were equivalent.

Further, with the 2-cut treatments, longer regrowth periods between first and second cuttings in the year of differential harvests did not contribute to better stand health, winter survival, and therefore higher yields in the uniform evaluation harvest. Thus, timothy response was different from that of smooth brome grass which was disadvantaged by short regrowth periods between first and second cuttings (Klebesadel 1997).

As the final regrowth periods between the final cutting and killing frost on 26 September 1981 shortened from 66 days (trtmts. 14, 21, 28) to 5 days (trtmts. 20, 27, 34), the yields in June 1982 became progressively lower (Fig. 19), indicating that later cuttings resulted in an increasingly adverse effect on stand health. Whether the inappropriate timing of those late harvests influenced only the pre-winter storage of food reserves, or whether, additionally, removal of the foliage that serves as

receptor for photoperiod/nyctoperiod influences on pre-winter development of freeze tolerance was at a critically inopportune time is not known.

This pattern of late harvest effects on timothy stand health in Exp. VIII parallels the findings of Halling (1988) at 59°49'N in Sweden who compared five dates of second cuttings of timothy from 23–24 August to 4–5 October. Pre-winter sampling of shoots and stem bases “when growth had ceased in autumn” showed a regular and progressive decrease in total nonstructural carbohydrates (TNC) from first to last date of second cutting. The longer pre-winter regrowth periods afforded by earlier second cuttings resulted not only in higher TNC levels in overwintering tissues prior to winter, but significant correlations were found between high pre-winter TNC levels and initial growth rate of the grass the following spring (Halling 1988).

Similarly, Østgard (1962), reporting on timothy management near 70°N in northern Norway, stated that “aftermath cutting or grazing in the autumn tends to weaken timothy’s resistance to winter.”

These three instances of harmful effects on timothy persistence occasioned by inappropriate timing of late-season harvests all pertain to experimental results at high latitudes. Reports from lower latitudes refer instead to harmful effects on timothy persistence caused by timing of first cuttings. Several investigators in North America have reported poorer persistence of timothy when first cutting was near early head stage than when cut at early flowering stage (Brown *et al.* 1968; Knievel *et al.* 1971; Knoblauch *et al.* 1955). Some studies found that harvest effects were exacerbated with increasing rates of applied fertilizer N (Brown *et al.* 1968; Jung and Kocher 1974; Kunelius *et al.* 1976).

Grant (1971) in New Brunswick reported similar harmful effects on timothy haplocorm (corm) formation and stand persistence with high N and first harvest at boot stage; delaying first cutting to early flowering stage and fertilizing with potassium to maintain tissue N:K ratio close to 1:1 improved vegetative reproduction and productive life of stands. Peters (1958) noted also that a higher rate of applied N magnified the harmful effects of frequent cutting of timothy (4 cuts/year).

### **Differing Views on Tolerance of Timothy to Harvest Frequencies**

Brown *et al.* (1968), discussing timothy performance in the northeastern U.S. stated: “Timothy is a typical hay-type plant, with relatively few basal leaves below normal grazing height.” They also commented, citing other reports from mid-temperate areas for confirmation:



Figure 20. Individual plants of timothy cultivars (left to right) *Engmo*, *Climax*, and *Clair*. All were seeded 21 May; photo taken 3 October of same year. Numbers on stake indicate height in feet. Note greater concentration of basal leaves in the *Engmo* plant.

“Numerous experiments have shown timothy to be relatively intolerant of close, and/or frequent defoliation.” Peters (1958) reported adverse effects of short, frequent cutting on timothy in Wisconsin. Similarly, Hanson (1972) described timothy as “—not resistant to close, continuous grazing.”

Jung and Kocher (1974) in Pennsylvania reported more winter injury of timothy cultivars *Climax* and *Clair* after four cuttings per year than with three. Similarly, Schmidt and Tenpas (1960) in northern Wisconsin noted thinning and weakening of timothy stands that had been harvested four times per year for three years but not with two harvests per year. Peters (1958), also in Wisconsin, harvested timothy 2, 3, and 4 times per year and found harmful effects with most frequent harvests; the number of dead culms in plants increased with increasing harvest frequency. Smith *et al.* (1986) in the U.S. Midwest also cited as a disadvantage of timothy: “Easily weakened by heavy grazing or frequent cutting.” Harrison and Hodgson (1939) in Michigan, evaluating five different grass species for tolerance to frequent, close clipping, stated: “—they rated in

the following order, beginning with the one least injured: Kentucky bluegrass, quack grass, smooth brome grass, with timothy and orchard grass being about equal.”

Those preceding observations concerning the intolerance of timothy to frequent, close defoliation, and the latter ranking of smooth brome grass and timothy, are opposite of findings in Alaska. In a comparison at this location of several tall-growing grasses that included *Engmo* timothy and *Polar* brome grass, timothy exhibited better subsequent winter survival when harvested frequently (3 to 4 times per year) than when harvested twice; in contrast, smooth brome grass survived best after two harvests per year but was weakened and progressively more winter-injured following increasing frequency of harvests (3 or 4 times per year) (Klebesadel 1994b, 1997).

### Two Growth Types of Timothy

The above comments by investigators in the more southern conterminous U.S., attesting to the intolerance of timothy to close or frequent harvest or grazing, are based on timothy of a distinctly different growth form

or morphological type than the subarctic-adapted cultivars from northern Scandinavia and Iceland. Those North American cultivars with relatively few basal leaves (Fig. 20) respond more like smooth brome grass which is relatively intolerant of frequent cuttings (Harrison and Hodgson 1939; Klebesadel 1997), especially less tolerant than far-north European timothies such as Engmo with their abundance of basal leaves that suit them better to frequent (4 cuts) than to infrequent harvest (2 cuts) (Klebesadel 1994b). The most winterhardy of the subarctic-adapted cultivars (e.g. Engmo, Bodin, Korpa, Adda) possess an abundance of basal leaves similar to turfgrasses such as Kentucky bluegrass and red fescue.

Thus, unlike North American timothies that are more completely defoliated with close or frequent harvest, the far-northern European timothy type retains a considerable quantity of leaves below mower or grazing height. That retention of basal leaves permits those cultivars to tolerate frequent, close removal of topgrowth above a clipping or grazing height without weakening or otherwise disadvantaging the plants (Figs. 21, 22, 23). In fact, quite the opposite is apparent; in Exp. VIII plots of Engmo harvested only twice per year with a late second cutting (and in Exp. I of Klebesadel 1994b) were more

injured by the subsequent winter than plots harvested more frequently.

Further evidence of tolerance of Engmo to close and frequent clipping was seen in the 4-foot wide alleys between blocks of plots in Exps. VIII and IX. Both experiments had been broadcast-seeded over the entire study area so that the alleys were seeded identical to the plots. Throughout the year of differential harvests those alleys were clipped to a short (about 2 1/2-inch) turf about weekly using a rotary-blade, bagger-type lawn mower. In the following year of evaluation harvests, timothy growth in those alleys was as vigorous as in the best plots (Fig. 21).

Harrison and Hodgson (1939) in Michigan found Kentucky bluegrass most tolerant of close, frequent defoliation of five cool-season grasses, and the North-American type of timothy to be one of the least tolerant. Referring to the more complete defoliation of the taller-growing grasses, they stated: "After all of the green leaves have been removed from a grass plant, new growth is initiated at the expense of carbohydrates previously stored in some remaining part of the plant —Bluegrass withstood close cutting better than the other grasses because —it produced the most green leaves below the (clipping) height of 1 inch."



*Figure 21. Plot comparison in Exp. VIII photographed 1 June 1982 showing harmful effect on Engmo timothy of infrequent harvest during the previous year. Weakened and thinned plot left of center was harvested twice (30 June + 21 Sep. = trtmt. 34) in 1981; vigorous thick stand in plot right of center was harvested three times (10 June + 22 July + 21 Sep. = trtmt. 13) in 1981. Similarly vigorous growth across entire photo in foreground was an alley (between blocks of plots) that was clipped short (about 2 1/2-inch height) about weekly throughout the 1981 growing season.*

That relationship of grass morphology and cutting frequency explains why the far–northern European timothies with their abundance of basal leaves resemble in growth, and tolerate close, frequent clipping, more like Kentucky bluegrass than like North American timothies (Fig. 22).

Azzaroli and Skjelvåg (1981) in Norway studied the effects of two versus four cuttings (3– to 4–cm clipping height) and three rates of fertilizer application on tolerance to freezing in four species of potted grasses that included the Norwegian timothy cultivar Grinstad. They found that the more frequent cutting (28 May + 5 July + 3 Aug. + 9 Sep.) did not lower the freeze tolerance of that northern–type timothy compared with two cuttings (11 June + 31 July).

### Food–Reserve Levels and Tolerance of Harvest Frequencies

As noted in Exp. V, high pre–winter levels of carbohydrate food reserves in overwintering tissues were associated with best winter survival. Additionally, food reserves in timothy fluctuate throughout the growing season as influenced by plant developmental stages and removal of herbage in harvests as those influences cause

reductions or restoration of reserves (Reynolds and Smith 1962). Their report shows sharp declines in carbohydrate reserves after each forage harvest of North American timothy (that leaves a virtually leafless stubble) because reserves are drawn upon to put forth new tiller and foliar (photosynthetic) growth.

In contrast, far–northern timothies with a profusion of basal leaves (Figs. 20, 22), even if harvested frequently, have a continuous supply of photosynthetically active leaves left intact below clipping height. It is likely that future work on the seasonal levels of carbohydrate reserves in such plants will not show the sharp drops in reserve levels following harvest that Reynolds and Smith (1962) found with North American timothy.

Ward and Blaser (1961) and Smith (1974) reported that the presence of residual leaves can be equally beneficial to, or even more important than, carbohydrate reserves in fostering the rate of grass regrowth. Thus, the residual basal leaves present after frequent harvests of far–northern timothies can maintain continuous photosynthetic activity, assist in promoting active regrowth, and probably circumvent the sharp post–harvest food–reserve declines that occur in North American timothies.

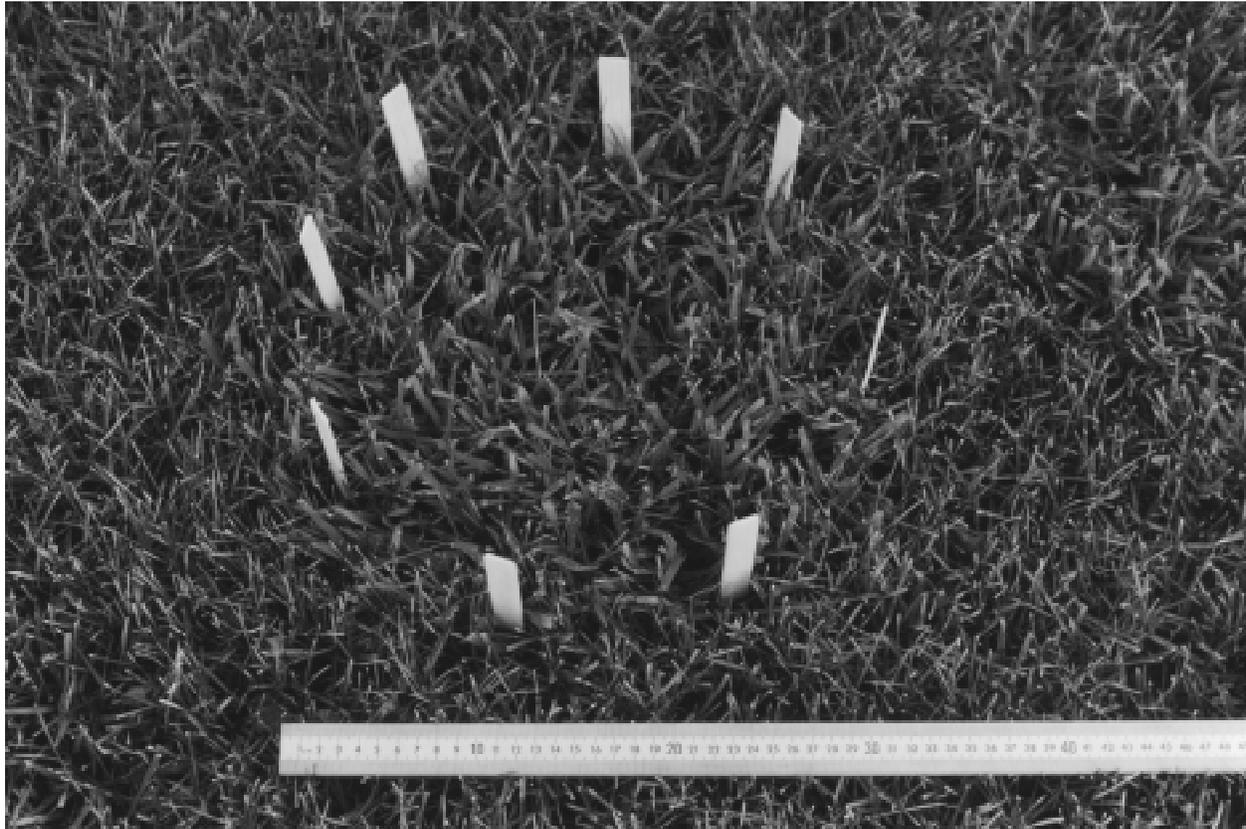


Figure 22. A several–year–old plant of Engmo timothy (ringed by white stakes) in a Kentucky bluegrass lawn, showing that this timothy from northern Norway, with an abundance of basal leaves, thrives in turf clipped back regularly to about a 2–inch height.



*Figure 23. Two-acre field of Engmo timothy near Palmer that was planted about 1965 and harvested for hay through 1969. For the next 28 years (1970 through 1997) it has been mowed continuously as a relatively coarse turf (clipping height about 2 1/2 inches) with no harmful effects on stand. Field location is away from winter wind path, thus protective snow cover remains in place.*

The harmful effects from infrequent harvesting of far-northern timothies likely is due to heavy shading of the basal leaves that causes their bleaching and senescence as noted in plots harvested infrequently. Such plants have then lost the benefit of continuous photosynthetic activity and are thus caused to behave like North American timothies that must draw more heavily on stored reserves to put forth new growth.

## **CONCLUSIONS**

Comparisons of many timothy cultivars adapted in various North American and northern European growing areas, a geographical extent spanning over 30 degrees of latitude (from about 38°N to 70°N), showed a clear relationship between latitude of origin and winter survival in Alaska. Poorest survival occurred with cultivars from the most southerly origins in North America. Increasingly better winterhardiness was exhibited by strains of progressively more northern

adaptation, and consistently best survival occurred with cultivars from the northernmost areas of timothy culture in Norway and Iceland.

For best winter survival, therefore, Alaska growers should utilize far-northern-adapted strains that have demonstrated superior winterhardiness in several tests reported herein; those include the cultivars Engmo, Bodin, and Va-BL-60 from northern Norway, and Korpa and Adda from Iceland.

Evans (1937) stated: “—a certain variety of timothy may be adapted only to a more or less restricted area.” That contention could be interpreted to mean that a variety cannot be expected to perform well outside a limited geographical area. Yet Engmo and other far-northern-adapted timothy strains from northern Norway and Iceland generally are well adapted for use in Alaska, thousands of miles from their origins, but at near-similar latitudes and where climatic conditions are relatively analogous. Thus, a more accurate statement, with greater recognition of plant/en-

vironment harmony, might be: “Cultivars moved to climatic, photoperiodic, and other growing conditions too different from circumstances in their area of adaptation may not perform to their full potential.”

Reasons for the better performance in Alaska of northernmost-adapted timothy strains than those of more southern adaptation were found in comparisons of representative cultivars adapted at widely separated latitudes. Best winterhardiness in this area was associated with (a) northernmost adaptation, (b) the ability to store a high pre-winter level of food reserves, (c) achievement of a high percent dry matter and a high level of freeze tolerance in overwintering crown tissues prior to onset of winter, and (d) assumption of a desirable state of dormancy (cessation of growth) well before freeze-up. The cultivar from the most southern latitudinal origin was poorest in all of these criteria, while the one adapted at an intermediate latitude was intermediate in the same characteristics.

Even the most northern-adapted and most winterhardy cultivars of timothy are more susceptible to severe injury or total winterkill than the most winterhardy strains within several other forage-grass species that are rhizomatous. The more-exposed overwintering tissues of timothy plant crowns at the soil surface render them more susceptible to winter stresses than the better protected, underground overwintering tissues of rhizomatous species such as smooth brome grass, Kentucky bluegrass, creeping foxtail, and red fescue.

Insulating snow cover enhanced timothy winter survival markedly, especially marginally winterhardy cultivars. Winter-injured timothy plants, if not excessively damaged, displayed a remarkable ability to recover during the growing season and produce good second-cutting forage yields.

With two harvests per year, the regrowth (after the first cutting) of the northernmost European cultivars produced few headed culms, consisting almost entirely of leafy herbage. In contrast, cultivars from Canadian and U.S. origins produced higher-yielding regrowths of taller, head-bearing, extended culms. Cultivars from intermediate latitudinal sources in Scandinavia produced regrowth intermediate between the above extremes.

As a result of the tendency toward winter injury in North American strains and the above differences in type of regrowth after the first cutting, northernmost-adapted European cultivars generally produced higher yield in the first cutting while those from North America often were higher yielding in the second cutting.

In contrast to poor herbage production during the hot portion of growing seasons at more southern latitudes, timothy is well adapted for vigorous, productive growth throughout the relatively cool growing seasons of this area. However, to realize maximum productive potential in Alaska, timothy must escape winter injury and be well supplied with soil moisture and soil fertility.

The one-experiment exploratory study with Engmo timothy on the effects of three planting dates (mid-May, 1 June, mid-June) and six seeding-year harvest dates (22 Aug. to 9 Oct.) showed that both procedures influenced seeding-year forage yields as well as first-cut yields the following year.

Higher seeding-year forage yields were obtained from Engmo stands planted in mid-May than 1 June; seeding-year yields from both of those planting dates were much higher than from timothy planted in mid-June. Seeding-year harvest in late August harmed mid-June-planted Engmo less than five later harvest dates, but that late-August forage yield was very low. Mid-June-planted Engmo harvested later than early September in the seeding year was predisposed to considerable winter injury.

These preliminary results suggest that, for timothy planted without a companion crop, best seeding-year forage yield, coupled with good winter survival, should be realized with planting no later than late May and with the seeding-year harvest no later than late August.

The generally good tolerance of established Engmo timothy to more frequent harvests than two per year, as shown in these experiments and in an earlier report (Klebesadel 1994b), contrasts with many published reports on timothy management at lower latitudes that show North American cultivars tolerate poorly more than two cuttings per year. Engmo's tolerance of several cuttings per year also differs from smooth brome grass, the other dominant perennial forage grass in this area, which withstands two harvests much better than more cuttings per year (Klebesadel 1994a, 1994b, 1997).

The profusion of basal leaves in the far-northern timothy cultivars derived from Iceland and northern Norway permit ongoing photosynthetic activity with frequent cuttings. Thus, they function more like turfgrasses than like North American timothies and other tall grasses that, when harvested, must draw heavily upon stored reserves to initiate new leaf growth before photosynthetic activity can resume.

Exps. VIII and IX illustrate the forage yields that may be expected from established Engmo timothy

with good winter survival and relatively high rate of fertilizer topdressing when harvested on various schedules and frequencies.

In general, lower yields were obtained with more frequent harvests, but the grass displayed good tolerance to frequent harvests. Other work at this location has shown Engmo herbage harvested three or four times per year was of very high quality (Klebesadel 1994b). This suggests that Engmo timothy is well suited for green-chop utilization and/or rotational pasture. Another report from this location (Klebesadel 1992b) has shown Engmo to provide a more uniform supply of herbage throughout the growing season than smooth brome grass, the most-used perennial forage grass in this area.

Of stands harvested twice in 1981 (Exp. VIII), highest yielders in 1982 (Fig. 19) were those that had earliest second cuttings in 1981. Those were treatments that allowed the longest uninterrupted pre-winter regrowth periods. Those treatments, however, had relatively low total yields in 1981 due to the low yields of the early second cuttings (Fig. 16).

The most harmful effects on stand health were seen with only two cuttings per year, especially when the second cutting was taken later than mid-to-late August.

The markedly different rates of regrowth after the early June harvests in Exps. VIII and IX revealed the critical importance of the height above the soil surface of the hidden growing points (shoot apices) within the culms when early herbage is removed. Other reports as well have noted that if the bulk of those growing points are below cutting height, regrowth after that first harvest will continue actively (Sheard 1968). However, if the majority of those growing points are elevated sufficiently within the culms to be removed in the harvest, further growth of those culms is prevented and regrowth that must be initiated from axillary buds within the plant crowns can be very slow to start.

Because (a) precipitation in this area is marginal for realizing the full productive potential of timothy, (b) the April, May, and June period of timothy's potentially highly productive initial growth of the year coincides with normally low amounts of precipitation, and (c) drouthy intervals at any time during the growing season are not uncommon, supplemental sprinkler irrigation should ensure good herbage production of timothy throughout the growing season.

The results found in the experiments reported here, confirming Engmo timothy's generally good tolerance

of frequent cutting, and its poor herbage production when under moisture stress, agree well with farm practice on one of the state's largest dairy farms, located about five miles from the site of these experiments. That operator has used Engmo timothy successfully as a dependable, frequently harvested green-chop forage for over two decades, using supplemental sprinkler irrigation to ensure against moisture stress.

When not winter-injured, timothy strains well supplied with soil moisture produced forage yields equivalent to other high-producing forage grass species.

Alpine timothy, even though adapted at high latitudes, displayed very poor winter survival in the unaccustomed wind-swept environment of open fields. It was deficient as a forage grass in other agronomic characteristics as well, producing comparatively few culms and a modest amount of herbage, even though well supplied with fertilizer nutrients.

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