Responses of Biennial Sweetclovers of Diverse Latitudinal Adaptation to Various Management Procedures in Alaska

Leslie J. Klebesadel
Emeritus Professor of Agronomy
Agricultural and Forestry Experiment Station
Palmer, Alaska

UNIVERSITY OF ALASKA FAIRBANKS
Agricultural and Forestry Experiment Station
School of Agriculture and Land Resources Management

Bulletin 98 June 1994

Table of Contents

List of Tables and Figures

Summary

This report summarizes eight experiments with sweetclover (*Melilotus* species). Objectives were (a) determine responses of numerous cultivars and strains, representing a wide range of latitudinal adaptation, to various management procedures, (b) identify management options that contribute to improved winter survival, (c) delineate management procedures for maximizing yields, nutritional value, and usefulness of sweetclover for forage production in Alaska, and (d) identify logical avenues for future management research with sweetclover in this north-latitude area.

Species of sweetclover included were biennial yellow (*M. officinalis*), biennial white (*M. alba*), and annual white (*M. alba* var. *annua*).

All experiments except one were conducted at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska; one experiment was conducted at the Fairbanks Experiment Farm (64.9°N) in central Alaska's Tanana Valley.

Experiment I - Time of Planting, Rows:

Four strains of biennial white sweetclover of diverse latitudinal adaptation, were planted in rows without a companion crop at 10-day intervals (from May to August) and thinned to individual plants during two consecutive years. Objectives were to determine influence of planting date on seeding-year phenological development, winter survival, and subsequent forage yield.

Strains used and latitudinal adaptation of each were: (a) The cultivar Spanish adapted at 35° to 48°N in the conterminous U.S., (b) the cultivar Arctic grown at 50° to 56°N in Canada, (c) an Alaskan selection (AK-Syn.1) derived principally from Arctic at 61.6°N, and (d) Matanuska white, a selection from a roadside population that has undergone many generations of adaptive modification at 61.6°N in southcentral Alaska.

- All strains flowered in the seeding year when planted prior to mid-June.
- Spanish winterkilled completely in both tests, regardless of planting dates. Winter survival of Arctic, and to a lesser extent AK-Syn.1, was usually best with planting in early July. Earlier planting resulted in tall growth resembling annual habit during the seeding year, followed by generally poorer winter survival. Winter survival of Matanuska white was best with earliest planting dates. All strains winterkilled completely when planted later than late July.
- Second-year forage yields were highest from AK-Syn.1, intermediate from Matanuska white, and lowest from Arctic. Yields changed little for each of the strains for planting dates from 10 May to 10 June, but declined rapidly for later planting dates. Second-year forage yields were lowest from rows planted on 21 July and none were obtained from rows planted on later dates due to total winterkill.
- Herbage yield per surviving plant the year after planting was highest with earliest planting and gradually lower with progressively later planting dates.
- Natural selection in Alaska toward improved adaptation has resulted in (a) a sweetclover population (Matanuska white) with winter survival unaffected by flowering during the seeding year, and (b) a selection (AK-Syn.1) derived primarily from Arctic that was consistently superior to Arctic in winter survival.

Experiment II - Influence of Seeding-Year Harvest vs. Non-Harvest on Subsequent Winter Survival of 10 Strains of Biennial Sweetclover:

- The southernmost-adapted cultivars Denta, Spanish, and Goldtop winterkilled 100%, whether harvested or not in late September.
- Cultivars Cumino, Erector, and Madrid winterkilled 100% where harvested, and survived at very low rates (<8%) where not harvested.
- Winter survival was better with more northern-adapted strains but seeding-year harvest invariably and in some cases markedly decreased winter survival of those strains. Percents winter survival in rows harvested vs. not harvested, respectively, were: Arctic 55% and 73%, AK-Syn.1 75% and 86%, Matanuska white 83% and 89%, and Arctic Circle strain 40% and 78%.

Experiment III - Effects of Time of Seeding-Year Harvest on Seeding-Year Forage Yields, Winter Survival, and Second-Year Forage Yields:

- Seeding-year forage yields of AK-Syn.1 biennial white sweetclover broadcast-seeded 8 June increased continuously with progressively later harvests at 10-day intervals from 0.04 T/A on 20 July to 2.52 T/A at final harvest on 20 September.
- Percent crude protein in seeding-year forage declined from 33.7% at 20 July harvest to 13.6% at 20 September harvest.
- Stored food reserves in roots (3 treatments sampled) were considerably higher where plants had no topgrowth removal until 6 October than where plants were harvested 10 August or 10 September; plants were slightly lower in stored food reserves following 10 September than 10 August harvest.
- Winter survival was modest following all seeding-year harvest dates, averaging 29%; best survival was 40% following earliest (20 July) harvest and poorest (11%) following harvest on 30 August.
- Plants were shortest and forage yields lowest in the second year where seeding-year harvest had been on 30 August. In general, plant heights and forage yields were increasingly higher where seeding-year topgrowth removal had been progressively earlier or later than 30 August, with tallest plants and highest yields occurring where seeding-year forage harvest had been earliest (20 July) or latest (6 October).

Experiment IV - Influences of Two Planting Dates on Seeding-Year Forage Yields, and on Proportions and Crude Protein Concentrations of Leaves and Stems in Herbage of 12 Strains:

- The annual Hubam and the southernmost-adapted biennial cultivars (which grew tallest) produced highest seeding-year forage yields.
- Forage of the tallest-growing cultivars, especially the annual Hubam, was comprised of lower percentages of leaves and higher percentages of stems than the shorter-growing strains.
- Plants of all strains in the earlier-planted (25 May) rows were both taller and contained lower percentages of leaves at the 21 September harvest than plants in later-planted (12 June) rows.
- Over all strains and both planting dates, mean percent crude protein was 24.0% in leaves and 6.8% in stems at harvest on 21 September.
- Percent crude protein at harvest on 21 September was slightly higher in both leaves and stems (25.9% and 7.7%, respectively) of later-planted (12 June) rows than in rows planted 25 May (22.2% for leaves and 5.9% for stems).
- With all strains, forage yields harvested 21 September generally were much higher from rows planted 25 May than those planted 12 June; although later planting reduced the growing period by only 15%, mean forage yields were reduced 30%.

Experiment V - Annual Forage Production of Madrid Sweetclover as Influenced by Three Planting Dates and Various Row Spacings vs. Broadcast Seeding:

- Seeding-year forage yields on 21 September were highest with earliest (10 May) planting, intermediate with intermediate planting date (29 May), and lowest with latest planting (16 June).
- Planting in rows 18 inches apart resulted in generally higher forage yields, with all three planting dates, than broadcast seeding or rows planted 12, 24, or 30 inches apart.

Experiments VI, VII, and VIII - Seeding-Year Forage Production of 11 Diversely Adapted Strains Seeded on Different Dates in Three Different Years:

- Seeding-year forage yields of all 11 strains were highest in the year that planting was earliest (20 May), and lowest in the year that planting was latest (9 June).
- The annual Hubam, and cultivars of both white and yellow biennial sweetclover that were farthest from their latitude-of-adaptation (when grown in Alaska), grew tallest and produced highest forage yields.

General Summary and Recommendations

- Lowered winter survival resulting from utilization of biennial sweetclover (spring-seeded without a companion crop) for forage in the seeding year suggests that attempts generally will not be successful that seek to utilize the crop for maximum forage production in both years of its growth. Therefore, it appears that sweetclover culture in this high-latitude area can be conducted in either of two distinct ways, each with a very different type of sweetclover strain. Those two avenues are:
- **(a) Annual forage production:** Plant nonhardy, tall-growing, leafy, southern-adapted, low-coumarin cultivars as early as possible in rows about 18 inches apart with effective weed control. Expect no winter survival.
- **(b) Utilization as a biennial for second-year forage production:** Seed early and use the most winterhardy biennial sweetclover strains planted in association with a cereal companion crop. The companion crop should be removed at an immature stage for forage leaving a tall stubble. Early seeding and early companion-crop harvest can guard against damaging effects of companion-crop lodging and provide a longer late-summer period for sweetclover seedling growth free of the cereal crop competition. Leaving a tall stubble insures against injurious, too-short clipping of sweetclover seedlings; moreover, tall stubble holds protective, insulating snow cover in place against the removal force of strong winter winds.

INTRODUCTION

Only the most winterhardy forage crops survive consistently the rigorous winters in southcentral Alaska. Adapted grasses are more winterhardy than forage legumes in this area (Klebesadel 1992a, 1993d) and are used almost exclusively for perennial forage production. Nonetheless, identification of adequately winterhardy legumes for use alone or in mixtures with grasses for forage and for other purposes would be desirable.

Numerous legumes, including sweetclovers (*Melilotus* species), are widely used elsewhere and are valued for their contribution of biological nitrogen fixation, for their generally good palatability and nutritional value to consuming livestock as pasture or harvested forage, for soil improvement, as nectar sources for honeybees, for cover and food sources for wildlife, as attractive groundcovers, and for soil stabilization and erosion control (Graham 1941; Goplen and Gross 1977; Hollowell 1959; Smith *et al.* 1986; Smith and Gorz 1965).

Sweetclover Characteristics and Adaptation

Acreage of biennial sweetclovers in the northern U.S. has declined during recent decades (Hollowell 1959; Smith *et al.* 1986). Reasons include (a) expanded use of the longer-lived alfalfa, (b) damage to sweetclover from the sweetclover weevil (*Sitona cylindricollis*), and (c) the presence of coumarin in herbage of traditionally used sweetclover strains and cultivars.

Coumarin imparts a bitter taste to sweetclover forage, reduces palatability somewhat, and can cause "bleeding disease" in livestock that consume spoiled sweetclover hay or silage (Goplen and Gross 1977; Hollowell 1959; Smith *et al.* 1986; Smith and Gorz 1965).

Development of new, low-coumarin cultivars such as Denta in Wisconsin and Polara in Saskatchewan, however, can circumvent problems associated with that compound. Although those cultivars are inadequately winterhardy for use as biennials in Alaska (Klebesadel 1992b), they could be useful for forage production as annuals.

Sweetclover grows best on well drained soils that are alkaline, neutral, or only slightly acidic (Goplen and Gross 1977; Hollowell 1959; Smith *et al.* 1986; Smith and Gorz 1965). It is less tolerant of soil acidity than most grasses, alfalfa, or red clover (Smith *et al.* 1986). Therefore, in Alaska sweetclover should be well suited to parts of the Tanana, Matanuska, and Copper River Valleys where many agricultural soils are neutral to slightly acidic, but not to much of the Kenai Peninsula, Kodiak Island, or other areas where soils are more strongly acidic.

Winterhardiness

Bula and Smith (1954) reported that the most winterhardy strains among the major forage legumes are found in biennial white sweetclover (*M. alba*) and biennial yellow sweetclover (*M. officinalis*). Similarly, Ouellet (1976), in a survey of numerous Canadian stations, found biennial sweetclovers ranked highest in winterhardiness of the seven major forage legumes.

Work at this location during recent decades has shown that the most winterhardy biennial sweetclovers survive winters better than the most winterhardy strains of the true clovers (*Trifolium* species), birdsfoot trefoil (*Lotus corniculatus*), crownvetch (*Coronilla varia*), sainfoin (*Onobrychis viciaefolia*), and most alfalfas (*Medicago sativa*) (Klebesadel 1971, 1980, 1993d).

Therefore, biennial sweetclovers represent a logical choice for incorporation into forage production in Alaska if (a) dependably winterhardy strains can be identified or developed, and (b) appropriate management procedures can be formulated to maximize the productive potentials of sweetclover in the first and/or second year(s) of its growth.

Latitude-of-adaptation exerts a considerable influence upon winter survival of many introduced forage strains at this high latitude (Hodgson and Bula 1956; Klebesadel 1970, 1971, 1992a, 1992b, 1992c, 1993d). Similarly, sweetclover cultivars from the northern limits of culture of that crop in Canada are more winterhardy in Alaska than those from more southern sources (Hodgson and Bula 1956; Klebesadel 1992b, 1992c).

Latitudinal Ecotypes of Sweetclover

The term "ecotype" refers to a group or race of plants (within a species) in a given area that, through natural selection, have evolved to possess a genetically controlled physiology that is in harmony with its general environment (Wilsie 1962). There can be several different ecotypes within a species, especially within a species that occupies a large geographic range within which climatic conditions differ greatly.

The sweetclover strains evaluated in this report are viewed primarily as ecotypes as opposed to simply identifying them as cultivars (varieties); furthermore, they are sometimes referred to as "latitudinal ecotypes" to emphasize their adaptation at different global latitudes.

Sweetclover Culture in the Unique Photoclimate of High Latitudes

Earlier reports have identified biennial sweetclovers as unusually sensitive, especially during the first year of growth, to the daily duration of light and darkness (photoperiod and nyctoperiod, respectively). Those light/dark influences play a dominant role in determining (a) seeding-year flowering, (b) height of growth, (c) stem and root diameters, (d) development of crown buds, (e) fall dormancy, (f) pre-winter storage of food reserves, and (g) development of freeze tolerance (Kasperbauer *et al.* 1962, 1963a, 1963b; Klebesadel 1992b, 1993a; Smith 1942; Wiggans 1953).

Seasonal changes in photoperiod/nyctoperiod are magnified dramatically with increasing distance (measured as global latitude) north or south of the equator (Klebesadel 1985b). As a result, mid-summer photoperiods are considerably longer (and nyctoperiods shorter) in Alaska than in mid-temperate areas.

Sweetclover culture from antiquity to the present has been pursued within mid-temperate latitudes; thus these species are ideally adapted to growing conditions under which they have evolved. Even transferring sweetclovers thousands of miles from their areas of origin in Eurasia to North America kept these species within relatively similar latitudinal boundaries and therefore subjected them to little change in seasonal photoperiod/nyctoperiod patterns. Sweetclovers thus have evolved as a crop, have been selected and improved, and have had management practices formulated within relatively limited latitudinal boundaries where photoclimate and plant responses are very different from those occurring at Alaska's high latitudes.

When grown in Alaska, far north of their accustomed photoperiodic environment, seeding-year development of introduced biennial strains is more like annual sweetclover with tall, flowering growth on large-diameter mainstems and production of few and small crown buds in autumn (Klebesadel 1992b, 1992c, 1993a).

Those unusual seeding-year growth phenomena manifested by biennial sweetclovers when grown under the unique photoclimate at these high latitudes present Alaska growers with both opportunities and problems. Those differences in plant growth and development suggest that preferred management practices identified for sweetclover culture at more southern latitudes probably are inappropriate for Alaska.

Evaluation of various management procedures can illuminate how best to exploit sweetclover's unique growth at far-northern latitudes for optimum forage production and also to understand physiological behavior and limitations within sweetclover plants that are affected by both the north-latitude photoclimate and various management procedures that may be used.

Various observations have led to the belief that time-of-planting influenced winter survival of sweetclover at this location. Planting dates, and therefore time of seed germination and extent of seedling development prior to winter, have been found to influence winter survival of field pennycress (*Thlaspi arvense*), winter cereals, grasses, and alfalfa in this area (Klebesadel 1969a, 1969b, 1970, 1992a). Time of seeding-year harvest has also been suspected as a factor affecting winter survival of sweetclover.

Strains and cultivars evaluated and compared in experiments reported here represent a wide range of latitudinal adaptation. Most of the strains compared were cultivars from the northern U.S. and Canada. Three of the strains compared, however, represent selection in Alaska for improved winterhardiness and adaptation and a brief summary of their origins follows.

Adaptive Modification in Sweetclover Toward Improved Winterhardiness in the Subarctic

During earlier experimental evaluations of sweetclovers in the Alaska agronomy research program, three strains, two of biennial white and one of biennial yellow, have emerged that are superior in winterhardiness to all cultivars and strains of sweetclover compared from other world areas (Klebesadel 1992b, 1992c). Those three were included in experiments reported here; they are referred to as AK-Syn.1, Matanuska white, and Arctic Circle ecotype or strain.

AK-SYN.1, a biennial white strain, was selected in Alaska and derived primarily from the Canadian cultivar Arctic which in turn was selected at Saskatoon, Saskatchewan (ca. 52°N) from plants grown from seed collected near Semipalatinsk (50° to 51°N), Russia in 1913 (Hansen 1927). AK-Syn.1 represents the mass-selection product of successive generations of natural selection in field plots at the Matanuska Research Farm. Seed harvested from winter-surviving plants was seeded in new plots and the process repeated for three generations of selection for improved winter survival. No estimates were recorded of extent of winterkill in the successive generations. Except for being slightly shorter than Arctic during the seedling year, AK-Syn.1 otherwise closely resembles that cultivar.

AK-Syn.1 has surpassed Arctic in storing higher levels of food reserves prior to winter, in developing slightly higher levels of freeze tolerance, and in generally superior winter survival (Klebesadel 1992b).

Matanuska White is a mass-selection strain from a population that evolved over many generational cycles under subarctic natural selection pressures along a Matanuska Valley roadside (Klebesadel 1992b). It differs from all other biennial white strains and cultivars compared at this location in its shorter plant height, smaller mainstem diameter, and more numerous and larger crown buds in autumn; those growth characteristics are typical of all biennial sweetclovers when grown at more southern latitudes where they are adapted.

Matanuska white develops pre-winter freeze tolerance about equal to Arctic and AK-Syn.1, but develops greater dormancy in autumn than those strains (Klebesadel 1992b, 1993a). Comparative winter survival of Matanuska white vs. those two strains in field experiments has been dissimilar from year to year; it is believed that the different winter-habitat conditions under which the strains evolved, and the dissimilar nature of stresses imposed during different winters may account for the observed differences in winter survival. Matanuska white evolved in a roadside habitat benefiting from insulating snow cover and therefore not subjected to the direct cold and desiccation stresses of open field environments where AK-Syn.1 was selected.

The greater pre-winter dormancy exhibited by Matanuska white apparently was acquired through natural selection as a beneficial adaptive characteristic during 30 or more years in this subarctic roadside environment (Klebesadel 1992b). Onset of that dormancy occurs late in the growing season in response to shortening daily photoperiods (lengthening nyctoperiods) rather than lowering temperatures (Klebesadel 1993a). That dormancy may be merely a characteristic that inhibits bud elongation during the seedling year, or it may be a more encompassing and protective physiological mechanism that assists in preventing de-hardening during mid-winter. This characteristic was acquired in an environment frequently subjected to wide oscillations of winter temperatures with commonly occurring thaw periods of +40° to +45°F that sometimes last for several days before refreezing occurs (Dale 1956; Klebesadel 1974).

The **Arctic Circle Strain** represents a mass-selection from a garden site in the Alaska village of Fort Yukon (66.6°N), six miles above the Arctic Circle (Klebesadel 1992c). That population of biennial yellow sweetclover had undergone unattended natural selection for improved winter survival for about 15 years in an interior-basin locality where the mean January temperature is –21.6°F, and the record minimum is -66°F. During the pre-winter hardening period, that strain stores high levels of food reserves earlier, and develops higher levels of freeze tolerance and dry-matter concentration in overwintering tissues, than all other biennial yellow sweetclover cultivars compared. As a result of those indicators of superior physiologic adaptation, it displays markedly better winter survival in Alaska than cultivars adapted to more southern latitudes (Klebesadel 1992c).

These experiments

The several experiments summarized in this report were undertaken to explore the effects of various management options, and timing of various procedures, on sweetclover performance in Alaska. Objectives were to identify procedures for optimum management of sweetclover at this high latitude with the aim of incorporating this legume into forage production programs in Alaska.

Evaluative criteria included seeding-year development, seeding-year forage yields and quality, winter survival, and second-year forage production of numerous strains. Seven experiments reported here were conducted at the University of Alaska's Matanuska Research Farm (61.6°N) near Palmer in southcentral Alaska, and one (Experiment III) at the Fairbanks Experiment Farm (64.9°N) near Fairbanks.

EXPERIMENTAL PROCEDURES

Seven of the eight experiments in this report were conducted in Knik silt loam soil (Typic Cryochrept) and the other in Tanana silt loam (Histic Pergelic Cryaquept); all were in field areas with good surface drainage. Preplant commercial fertilizer disked into plowed seedbeds supplied nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) at 32, 128, and 64 lb/A, respectively, unless otherwise noted. Commercial bacterial (*Rhizobium*) inoculant for sweetclover was mixed with all seed samples immediately before planting. All row seedings were made with a seeder with a press-wheel that compressed the soil directly over the shallowly planted seed (⅛" to ½" deep). All broadcast-seeded plots were hand seeded onto a firm seedbed. Seed was buried shallowly (⅛" to ½") by lightly stirring the soil surface, then the seedbed was compacted firmly by drawing an empty corrugated-roller seeder over plots; tractor wheels were adjusted to travel on plot borders. A pre-emergence application of dinoseb (dinitro-o-sec-butylphenol)in water solution was applied uniformly over each experimental area 1 to 3 days after seeding to control broadleaf weeds.

At each harvest, a 15-inch swath was clipped and discarded from both ends of all rows and plots to remove border effects. Stubble height left with all harvests was about two inches unless otherwise stated. A representative sample was withdrawn from the total herbage harvested from each row or plot, placed into a cloth bag, weighed immediately, then dried to constant weight in a forced-air dryer at 140°F. Percent dry matter so derived, and sample area harvested, were used to calculate forage yields in oven-dry tons per acre. All indications of statistical significance are at 95% confidence limits unless otherwise noted. Specific strains used and procedural details not covered by the aforementioned general procedures are set forth in the description of each experiment that follows.

Experiments Ia and Ib—

Effects of 10 Planting Dates on Seeding-Year Development, Winter Survival, and Second-Year Forage Yields of Four Biennial White Sweetclover Strains of Diverse Latitudinal Adaptation: Two field experiments were seeded in two consecutive years in separate but adjacent areas, Exp. Ia in 1964 and Exp. Ib in 1965. Commercial fertilizer disked into the plowed seedbed prior to the first planting each year supplied N, P_2O_5, and K_2O at 28, 114, and 55 lb/acre, respectively.

The four strains were seeded at approximately 10-day intervals from May through August in both years (Table 1). Strains were (a) Matanuska white, (b) AK-Syn.1, (c) the Canadian cultivar Arctic, perpetuated for many years between approximately 50° and 56°N; and (d) the cultivar Spanish adapted at 35° to 48°N in the conterminous U.S.

A split-plot experimental design was used with four replications. Planting dates were utilized as whole plots and sweetclover strains as sub-plots. Each whole plot consisted of a single row of each of the four sweetclovers. Rows were 18 feet long and 20 inches apart. The first two plantings in Exp. Ia were made in dry surface soil and were sprinkle-irrigated to assure prompt germination. When seedlings from each planting attained a height of 1 to 2 inches, they were thinned by hand to leave individual seedlings 4 to 6 inches apart.

Plants were left intact at the end of the seedling year. Dead topgrowth was removed the following spring before new growth appeared. Each spring after the year of planting, experimental areas were topdressed to supply P_2O_5 and K_2O at 114 and 60 lb/acre, respectively. After new growth of overwintered plants was well underway, counts of living and dead plants were recorded in all rows.

Rows were harvested for forage yield leaving a 3-inch stubble in mid-July of the year after planting, except Matanuska white was not harvested in Exp. Ia and was left to produce a seed crop. Dry weight per plant was derived by dividing total oven-dry weight per row by the number of living plants harvested.

Experiment II—

Influence of Seeding-Year Harvest vs. Non-Harvest on Subsequent Winter Survival of 10 Strains of Biennial Sweetclover: Six strains of biennial white, one of annual white, and four of biennial yellow sweetclover were seeded in drilled rows 16 feet long and 24 inches apart on 9 June 1966.

Each strain was seeded in a pair of adjacent rows in each of four replications. On 29 September of the seeding year, one of each pair of rows was harvested for forage yield leaving a 2-inch stubble; those yields are presented later as Experiment VIII in this report. The uncut adjacent row of each strain pair was left unharvested until the following spring. On 18 May of the following year, after spring growth had initiated on living plants, all living and dead plants were counted in the center eight feet of each row to calculate percents winter survival.

Experiment III—

Effects of Time of Harvest on Seeding-Year Forage Yields, Winter Survival, and Second-Year Forage Yields: AK-Syn.1 sweetclover was broadcast-seeded 8 June 1965 in plots measuring 5 by 20 feet in lowland Tanana silt loam at the Fairbanks Experiment Farm. Each plot was harvested once in the seeding year with harvests at about 10-day intervals on seven dates from 20 July to 20 September. The sickle bar was fitted with lifters to leave a 6-inch stubble; this was done to leave regrowth sites at basal axils on the mainstems (Fergus 1958; Smith *et al.* 1986). One plot in each of the four replicates was left unharvested until after killing frost, and yield for that plot was not recorded.

Regrowth on previously harvested plots, and original growth on the previously unharvested plot, were all clipped to a 2-inch stubble on 6 October and the experimental area was raked clean. This was done to create a uniformly untenable, shelterless environment to discourage a sometimes high population of field voles (*Microtus* sp.) from remaining on the experimental area over winter. It was believed that they might have been attracted to nest and feed unevenly, favoring plots with more vegetative cover than others, thus damaging plants in some treatments more than others.

On 6 October of the seeding year, plants were dug from three plots in each replicate to determine if harvest treatments had influenced levels of stored food reserves. The three treatments selected for sampling were plots that had been harvested 10 August and 10 September, and plots unharvested until the 6 October digging date. Aerial growth beyond one inch above the cotyledonary node was severed immediately to arrest transpirational moisture loss and discarded. Taproot growth beyond four inches below the cotyledonary node and all branch roots were severed and discarded also. Roots were wrapped in moist toweling and, as rapidly as possible, samples were withdrawn for determinations of tissue dry-matter concentration, and stored food reserves.

Stored food-reserve measurements (as etiolated growth in darkness) were accomplished as follows: soil was washed from stem-base/crown/taproot segments (plants) with a cold-water spray to remove all traces of soil and plant debris; they were then surface-dried with absorbent toweling. A random sample of plants of each strain was withdrawn, weighed, dried to constant weight at 140°F, and reweighed. Percent dry matter derived thusly was used to calculate extrapolated dry weights of plants used for stored food-reserve determinations. Ten plants from each replicate were potted for each of the three harvest treatments sampled.

Plants were weighed individually and embedded vertically in moist vermiculite in plastic pots. Five plants were spaced evenly in each pot and embedded so that the cotyledonary nodes were just above the vermiculite surface. Pots were then placed into a warm (66°±2°F) dark chamber with the base of pots immersed in ¼ to ½ inch of water. A fungicide (parachloronitrobenzene) in water spray was applied to plants as needed, usually about three times weekly, to prevent mold development. Etiolated growth was harvested from plants at successive 2-week intervals until no more appeared; this point represented exhaustion of food reserves as plants died shortly thereafter. Etiolated growth was harvested back only to the lowermost node to ensure the presence of regenerative bud sites throughout the test period. Harvested etiolated growth was dried at 140°F and stored food reserves are reported as milligrams (mg) oven-dry etiolated growth per oven-dry gram (g) of plant storage tissue potted.

Sweetclover stand counts were made on 6 October of the seeding year, and on 10 June of the following spring. A rectangular frame measuring 1 by 2 feet was placed at eight random locations along the centerline of each plot on each date and all enclosed living plants were counted and recorded.

To measure effects of seeding-year harvest dates on second-year vigor and forage productivity of the sweetclover, a uniform evaluation harvest of all plots was taken on 11 July.

Experiment IV—

Influences of Two Planting Dates on Seeding-Year Forage Yields, and on Proportions and Crude Protein Concentrations of Leaves and Stems in Herbage of 12 Sweetclover Strains: Twelve strains of sweetclover (7 biennial white, 1 annual white, and 4 biennial yellow), identified in Tables 2 and 3, were drill-seeded in rows 16 feet long and 18 inches apart on 25 May and on 12 June 1967. Border rows were seeded at the outer edges of each date-of-plant main plot, and sweetclover strains were randomized as subplots with four replications.

All rows were harvested on 21 September. After a representative herbage sample from each row was dried to constant weight at 140°F in a large cloth bag, leaves and stems in each sample were separated and weighed separately, and each portion was ground finely and analyzed for crude protein (N x 6.25) using the Kjeldahl method.

Experiment V—

Annual Forage Production of Madrid Sweetclover as Influenced by Three Planting Dates and Various Row Spacings vs. Broadcast Seeding: The southern-adapted biennial yellow cultivar was planted on three different dates (10 May, 29 May, 16 June) in 1967 in broadcast-seeded plots measuring 6 by 20 feet and in similar-sized plots containing rows 20 feet long and spaced 12, 18, 24, and 30 inches apart. All rows and plots were harvested for forage on 21 September of the seeding year, leaving a 2-inch stubble. Forage yields were determined from a mower swath harvested through the centerline of broadcast-seeded plots, from the center two rows in plots with rows 12 and 18 inches apart, and from the center one row in plots with rows 24 and 30 inches apart. The different plot areas contributing to yield were considered in calculating per-acre yields.

Experiments VI, VII, and VIII—

Seeding-Year Forage Production of 11 Diversely Adapted Strains Seeded on Different Dates in Three Different Years: Eleven strains of white and yellow sweetclover (identified in Fig. 14) were seeded in rows in three different years to compare forage production in the seeding year. Exp. VI was seeded 20 May 1963 with rows 20 feet long and 24 inches apart using six replications, Exp. VII on 30 May 1964 with rows 18 feet long and 18 inches apart with six replications, and Exp. VIII on 9 June 1966 with rows 16 feet long and 24 inches apart with four replications.

One seeding-year forage harvest was made in each experiment near the end of the growing season (see growing periods, harvest dates, and other pertinent information in Fig. 14).

RESULTS AND DISCUSSION

Experiments Ia and Ib—

Effects of 10 Planting Dates on Seeding-Year Development, Winter Survival, and Second-Year Forage Yields of Four Biennial White Sweetclover Strains of Diverse Latitudinal Adaptation. Growth During Year of Planting: Germination and seedling emergence proceeded regularly during both seasons with most cotyledons emerging within 10 days after planting. Emergence of Matanuska white usually was slightly later than the other three strains. Moreover, seedling growth of Matanuska white was somewhat slower and shorter than the other strains (Table 1). Seedling growth of Spanish, the southernmost strain, was most rapid, thus producing the tallest plants; AK-Syn.1 and Arctic were intermediate and about equal in seedling vigor and height.

Table 1. Height and phenological development of four sweetclover strains on 4 October, near the end of the growing season, as influenced by 10 dates of planting during the same growing season (Exp. Ib).

Planting dates	Sweetclover strains Matanuska white	AK-Syn.1	Arctic	Spanish	Development[1]
	Height (inches)				
10 May	18-22	32-34	36-40	38-42	Many flowers, some green pods
20 May	18-20	30-34	36-40	38-42	Many flowers, some green pods
28 May	16-18	28-30	36-40	36-40	Many flowers, some green pods
10 June	16-18	24-26	28-30	30-34	Some flowers
22 June	12-14	20-22	22-24	26-30	Very few flowers, floral buds present
1 July	10-12	16-18	18-20	20-24	Vegetative, no buds
13 July	4-6	6-8	6-8	12-14	Vegetative, no buds
21 July	3-4	4-6	4-6	8-10	Vegetative, no buds
30 July	2-3	3-4	4-6	4-6	Vegetative, no buds
10 Aug	1-2	2-3	2-3	2-3	2 trifoliate leaves

[1] Developmental stages were generally similar for all strains.

General patterns of seedling growth and development of each strain, as influenced by planting date, were similar for both seasons. By mid-August, plants of all four strains from the 10 May planting (Exp. Ib) were beginning to flower; plants from the 20 May planting were in late bud to very early flower stage, and plants from the 28 May planting possessed numerous floral buds but had not started to flower. Descriptions of growth stages attained by plants by the end of the growing season were similar in both tests and are presented in Table 1. When growth terminated in autumn, seedlings from May plantings had many flowers and many seedlings planted in early June were beginning to flower.

Duration of daily dark periods or nights (nyctoperiods) is the critical environmental factor that governs flowering during the seedling year in biennial sweetclover (Kasperbauer *et al.* 1963a). Biennial sweetclover does not flower at mid-temperate latitudes because all nyctoperiods during the growing season are of sufficient duration to prevent flowering. At this subarctic latitude, in contrast, the period between sunset and sunrise at the summer solstice is only 4.5 hours, and this period is continuous twilight rather than true darkness. Therefore, biennial sweetclover planted prior to mid-June at this latitude is induced to flower during the same season because mid-summer nyctoperiods are of insufficient duration to prevent flowering.

Matanuska white differed somewhat in seedling growth morphology from the other three strains. In addition to being shorter, Matanuska white plants displayed relatively little dominance in the development of the mainstem and possessed well developed branches, especially near the base of the mainstem. Those branches grew horizontally rather than ascending as in the other strains. Lower branches of seedlings from late June and July plantings lay prostrate on the soil surface. In addition to branch growth on the mainstem, often about two of the crown buds elongated into short basal branches during the seedling year (Klebesadel 1993a).

The generally prostrate growth habit of individual spaced plants of Matanuska white has not been apparent in broadcast seedings or in drilled rows where interplant competition in those more dense stands restricts lateral growth of stem branches and causes more erect growth of this strain resembling typical sweetclover development. The spaced plants of the other three strains developed even larger branches from the mainstem than Matanuska white, but that development was not at the expense of the dominance of the much taller-growing mainstems in those strains (Table 1).

With early planting, considerable growth was achieved by the end of the seedling year by all four strains (Table 1). Although no seeding-year forage harvests were taken, there was potential for considerable forage yield at the end of the seeding year from earliest-seeded rows, especially the tallest-growing Spanish.

Winter Survival: No plants of Spanish survived either winter regardless of planting date. Winter survival of the other three strains declined precipitously with planting later than 10 July in both experiments (Figs. 1, 2). Winterkill of seedlings of all strains was complete with planting later than 30 July in Exp. Ia and 21 July in Exp. Ib. The small seedlings from plantings near mid-July and later sustained considerable winter-heaving damage. The resultant exposure of seedlings heaved from the soil undoubtedly contributed to the high incidence of winterkill in the late plantings.

The poor survival of late-planted sweetclover in this study agrees generally with other reports. In Saskatchewan, White and Horner (1943) seeded sweetclover at intervals from 1 September to freeze-up. Plants from the earliest seedings had three or more leaves prior to freeze-up and averaged only 15% winter survival over four years. Later plantings achieved less growth prior to freeze-up and winterkilled completely.

Arakeri and Schmid (1949) subjected sweetclover and other forage seedlings to -10°C (+14°F) for eight hours at various stages of development. Emerged sweetclover seedlings survived the freeze test no better than 6% at any stage during the first eight weeks of growth. When seven to nine leaves were present at nine weeks of age, survival increased abruptly to 62%.

In the present study, first killing frosts (28°F) of autumn occurred about 10 October during both experiments, and soil freezing occurred between 15 and 20 October in both years. Seedlings less than 10 to 11 weeks old at freeze-up did not survive the winters. Seedlings 12 to 13 weeks old before freeze-up displayed better, but mediocre, survival. With the slower growing Matanuska white, winter survival generally was best with the oldest seedlings. In contrast, maximum winter survival of Arctic and AK-Syn.1 occurred with seedlings that were 15 to 16 weeks old and 16 to 20 inches tall prior to freeze-up.

In another somewhat similar investigation at this location, A-Syn.B alfalfa seeded on seven different dates from late May to late July also was found to survive the following winter best when seeded in early July (Klebesadel 1992a).

Considering the May, June, and early July plantings in the present study, winter survival of Arctic and the two Alaska strains was somewhat better in Exp. Ib than in Exp. Ia (Figs. 1, 2). Regression lines for winter survival, as influenced by planting dates up to and including the first date in July of both seasons, are plotted for the three strains in Figures 1 and 2. For those planting dates, differences among strains were highly significant (1% level) in both tests. In the second test, survival differences among the six dates (1 July and earlier) were significant (5% level) and the interaction dates x strains was highly significant. A high coefficient of variability (48%) characterized survival data for the more severe winter during Exp. Ia, precluding statistical significance for differences in winter survival among dates and the dates x strain interaction.

Winter survival of Arctic in Exp. Ia was near 30% for the first planting date (Fig. 1). However, a trend toward increased survival of Arctic occurred with the next four

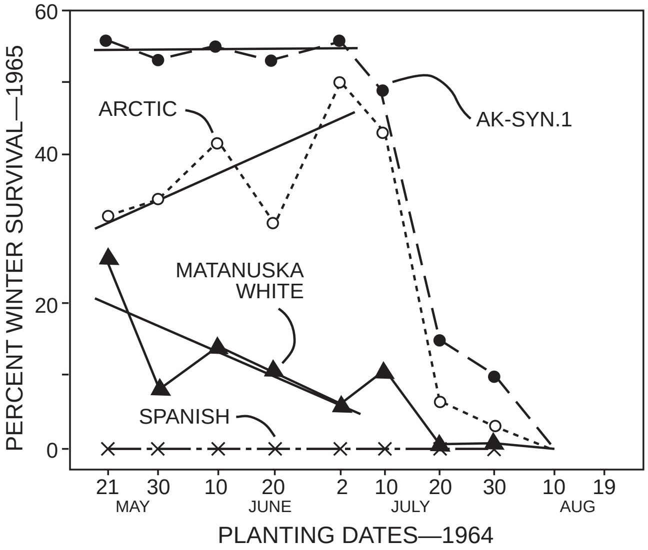


Figure 1. Percent winter survival of sweetclover strains in 1965 (following a relatively severe winter) as influenced by various planting dates in 1964. Linear regression lines drawn for first five planting dates with three strains that displayed differential survival (Exp. Ia).

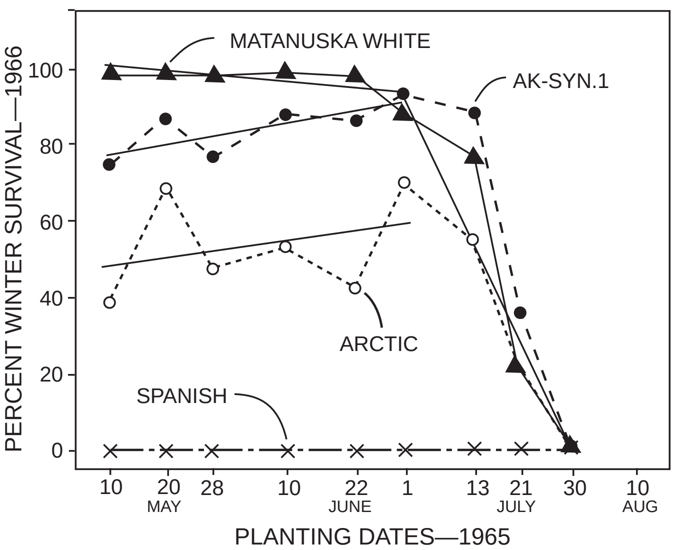


Figure 2. Percent winter survival of sweetclover strains in 1966 (following a milder winter than that of 1964-65) as influenced by various planting dates in 1965. Linear regression lines drawn for first six planting dates with the three strains that displayed differential survival (Exp. Ib).

planting dates, and maximum survival of 50% occurred with seedlings planted 2 July. A somewhat more erratic pattern of winter survival of Arctic was noted in Exp. Ib (Fig. 2). However, poorest survival from the first six dates of planting was 39% for the earliest date (10 May) while best survival of 70% occurred with planting on the latest of those six dates (1 July). The regression lines of percent winter survival for Arctic for planting dates up to early July inclined upward from 31% to 45% in Exp. Ia and from 48% to 59% in Exp. Ib.

Winter survival of AK-Syn.1 was always better than Arctic, the cultivar from which it was derived. Winter survival of AK-Syn.1 in Exp. Ia approximated 55% for all dates of planting from 21 May to 2 July (Fig. 1). Over the first six planting dates in Exp. Ib, winter survival increased gradually from 75% to 93% (Fig. 2).

Matanuska white displayed vastly dissimilar winter survival in the two tests. Best survival in Exp. Ia was only 26% with the earliest planting date and survival was progressively poorer with later planting dates (Fig. 1). In contrast, survival in Exp. Ib approximated 99% with all five earliest planting dates (Fig. 2). Winter survival of Matanuska white in the first test was considerably inferior to both Arctic and AK-Syn.1. Although survival of both Arctic and AK-Syn.1 was better in Exp. Ib than in Exp. Ia, Matanuska white nonetheless greatly surpassed those strains in the second test.

The reason for the strikingly dissimilar winter survival results in the two tests is believed related to the differential severity of the two winters and to dissimilar habitat conditions under which the different strains evolved. Minimum air temperatures were quite different during the two winters. Lowest daily minimums recorded during the first winter were -32° and -37°F within a 6-day period in mid-December; during that period all daily minima were lower than -12° and their mean was -27°F. That was followed by a 16-day period of sustained cold in late December/early January with all minima below -5°F, four consecutive days of which were -23° to -26°F.

In contrast, the lowest air temperature recorded during the second winter was -24°F during a mid-December cold period of only two days duration. Only two other brief, 3-day cold periods were recorded in mid-January and late February with minima of -22° and -19°F, respectively.

Matanuska white evolved in a roadside habitat where tall, uncut vegetation retained a protective, insulating snow cover even during severe winter winds. Moreover, snow removed from the adjacent roadway by snowplows deposited additional snow cover on the overwintering sweetclover. Matanuska white therefore evolved under conditions where selection for low winter temperatures was less rigorous than in open fields where AK-Syn.1 was selected principally for low-temperature tolerance.

The very low minimum temperatures over a prolonged period in Exp. Ia differed greatly from the better-protected roadside habitat and apparently were too low for good survival of Matanuska white. These results indicate that the Matanuska white strain is less able to tolerate extremely low temperatures (and desiccation stresses?) in the more exposed cropland habitat than strains that were selected under those conditions.

Flowering vs. Winter-Survival Relationships: Flowering of Matanuska white during the seeding year did not result in decreased survival during the subsequent winter (Figs. 1, 2). In contrast, Arctic in both tests, and AK-Syn.1 in Exp. Ib, showed generally poorer winter survival with early planting dates that resulted in profuse flowering during the seedling year. Best winter survival of those two strains occurred with seedlings

Figure 3. Second-year growth of sweetclover strains in Exp. Ib planted 1 July 1965 and photographed on harvest date (18 July 1966). Dead row just left of center is the southern-adapted cultivar Spanish. Abundantly flowering row to left of Spanish is Matanuska white. Taller rows to right of center are Arctic and AK-Syn.1. Winter survival of these rows was (left to right) 95%, 0%, 56%, and 92%.

that were planted in early July and had not flowered by the end of the growing season.

A similar pattern was noted at this location with field pennycress, a plant that behaves either as an annual or as a winter annual, depending on time of seed germination (Klebesadel 1969a). Pennycress plants that germinated near mid-season and did not flower in the seedling year, survived the winter better than earlier-germinating plants that flowered.

Inasmuch as all sweetclover seedlings that germinate early in the growing season in subarctic Alaska flower to some extent during the same season, there logically has been natural selection within the Matanuska white ecotype for winter survival despite flowering during the first season of growth. Such selection would not be operative in lower latitudes where shorter photoperiods/ longer nyctoperiods during the growing season generally preclude seeding-year flowering of biennial sweetclovers (Kasperbauer *et al.* 1963a).

Other investigators have studied the relationship of flowering and winter survival in other clover species. Reports from Wisconsin (Smith 1957, 1963; Therrien and Smith 1960) relate that red clover (*Trifolium pratense*) and alsike clover (*T. hybridum*) that flowered during the season of planting survived the subsequent winter poorer than seedlings that did not flower. Winter survival of red clover improved when flowering was prevented by late seeding (Smith 1957, 1963) or by removal of floral buds to prevent flowering (Therrien and Smith 1960).

For the first five planting dates in Exp. Ia and the first six in Exp. Ib, AK-Syn.1 and Arctic averaged 62% and 49% winter survival, respectively. These results indicate that only three generations of natural selection were effective in raising the level of sweetclover winterhardiness for this locality. It is assumed that additional natural selection should further improve winterhardiness in AK-Syn.1. More comprehensive discussions of selection toward better winter survival of sweetclover at far northern latitudes are reported elsewhere (Klebesadel 1992b, 1992c).

These results parallel findings by Goplen (1971) in Canada with biennial yellow sweetclover. Natural selection within the cultivar Madrid when grown near 53.4°N, considerably north of its normal latitude of adaptation (35° to 50°N), resulted in the cultivar Yukon with much better winterhardiness in Canada than the original Madrid. Other parallels have been reported concerning natural selection acting upon introduced legumes to produce resultant populations possessing superior winterhardiness in Alaska (Klebesadel 1971, 1985a, 1986, 1992c).

Forage Yields: Arctic and AK-Syn.1 were harvested for forage yield in mid-July of the second year of growth in both tests (Fig. 3); surviving plants of Matanuska white were left to produce seed in Exp. Ia and were harvested only in Exp. Ib. Because Exp. Ib incorporated an earlier planting date (10 May) than Exp. Ia, because yields of AK-Syn.1 and Arctic were generally similar in the two tests, and because Matanuska white was harvested only in the second test, forage yields are presented only for Exp. Ib (Figs. 4, 5).

Second-year forage-yield differences were highly significant (1% level) for dates of planting, strains, and

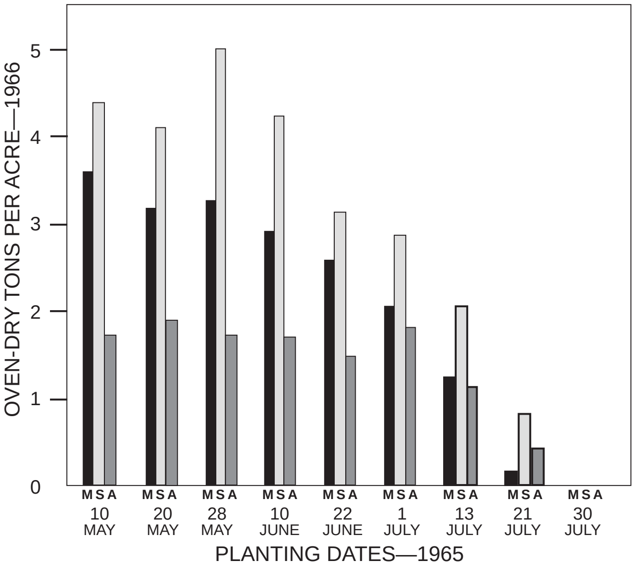


Figure 4. Second-year forage yields of three biennial white sweetclover strains as influenced by planting dates during the previous year: M = Matanuska white, S = AK-Syn.1, A = Arctic. These yields were to some extent favored by absence of competition when they occurred next to adjacent dead rows of the cultivar Spanish that winterkilled 100% with all dates of planting (Exp. Ib).

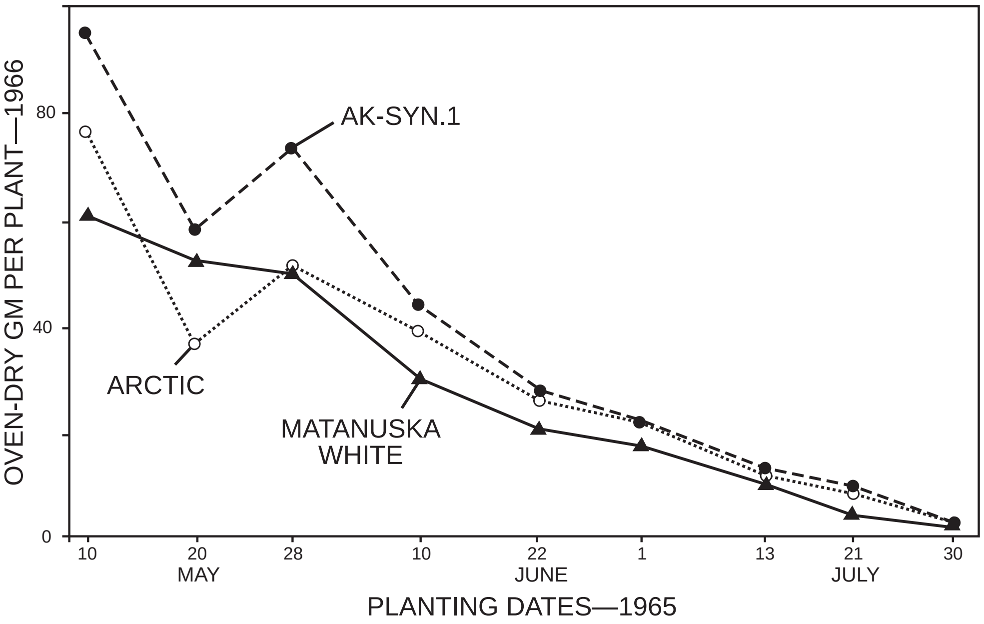


Figure 5. Herbage yield per surviving plant of three biennial white sweetclover strains at harvest on 18 July 1966 and as influenced by various planting dates during 1965 (Exp. Ib).

the dates x strains interaction (Fig. 4). Yields of AK-Syn.1 surpassed those of Matanuska white and Arctic with all eight planting dates that resulted in forage production in the second year (10 May through 21 July). AK-Syn.1 yields were approximately double those of Arctic with all planting dates, and yields of Matanuska white were intermediate between the other two strains.

Matanuska white yields generally declined regularly with each later date of planting, while yields of Arctic remained quite similar over all six of the first planting dates before declining with the last two. Yields of AK-Syn.1 did not differ greatly for the first four planting dates, but declined rapidly with planting dates later than 10 June.

Differences in yield per plant in Exp. Ia were highly significant for planting dates but were not statistically significant between the two strains, AK-Syn.1 and Arctic. Yield differences in Exp. Ib were highly significant for dates, strains, and the interaction (Fig. 5).

No explanation is apparent for the lowered per-plant yields for Arctic and AK-Syn.1 planted on 20 May. Otherwise, yield per plant of all three strains in the second year was highest with the earliest planting dates and followed a generally decreasing trend for successively later plantings until no survival occurred. Except for the 20 May planting, Matanuska white generally was lower in yield per plant than the other two strains. With planting dates prior to early June, AK-Syn.1 surpassed Arctic in yield per plant but, when planted 10 June and later, AK-Syn.1 and Arctic were very similar.

Experiment II—

Influence of Seeding-Year Harvest vs. Non-Harvest on Subsequent Winter Survival of 10 Strains of Biennial Sweetclover.

Seeding-year forage yields of the 10 biennial strains plus annual Hubam sweetclover harvested 29 September are reported as Exp. VIII and are included with seeding-year yields from two other experiments (VI and VII) discussed later in this report.

The tall growth left in place over winter on the alternate rows uncut in autumn effectively held insulating snow cover on the experimental area against the removal force of winter winds. Nonetheless only four of the 10 strains compared showed appreciable winter survival (Fig. 6); those were three biennial white strains (Arctic, AK-Syn.1, and Matanuska white) and the biennial yellow Arctic Circle strain.

The southernmost-adapted cultivars exhibited very poor winter survival. Denta, Spanish, and Goldtop winterkilled 100%, whether harvested or not in late September. Unharvested plants of Cumino, Erector, and Madrid survived slightly better when unharvested, but none survived as much as 8%; where harvested, Cumino survived at 2% and Erector and Madrid showed no survival.

Harvest of rows in September (vs. non-harvest) lowered winter survival only slightly in Matanuska white (83% vs. 89%), but harvesting was increasingly more harmful than non-harvest in AK-Syn.1 (75% vs. 86%), Arctic (55% vs. 73%), and the Arctic Circle strain (40% vs. 78%).

The reason(s) for the considerable differences in winter survival between harvested and uncut rows among the several northernmost-adapted strains is obscure. Harvesting caused only a 7% reduction in winter survival of Matanuska white, yet in the Arctic Circle ecotype, seeding-year harvest decreased winter survival by 49%. The presence of some prostrate branches with leaves that escaped harvest and remained functional in Matanuska white might explain the small difference in winter survival in that strain. However, plant morphology was relatively similar among AK-Syn.1, Arctic, and the Arctic Circle strain, yet harvesting of those caused quite dissimilar reductions in winter survival of 13%, 25%, and 49%, respectively (Fig. 6).

Inasmuch as the harvested rows alternated with unharvested rows, winter protection from insulating snow was similar for all rows, because the tall growth on uncut rows held snow in place against the removal force of winter winds. Therefore, the differences in winter survival between harvested and unharvested rows was due only to topgrowth removal and not to differential winter exposure.

This suggests that other factors involved with harvest logically contributed to decreased winter survival, such as (a) topgrowth removal occurred before all func-

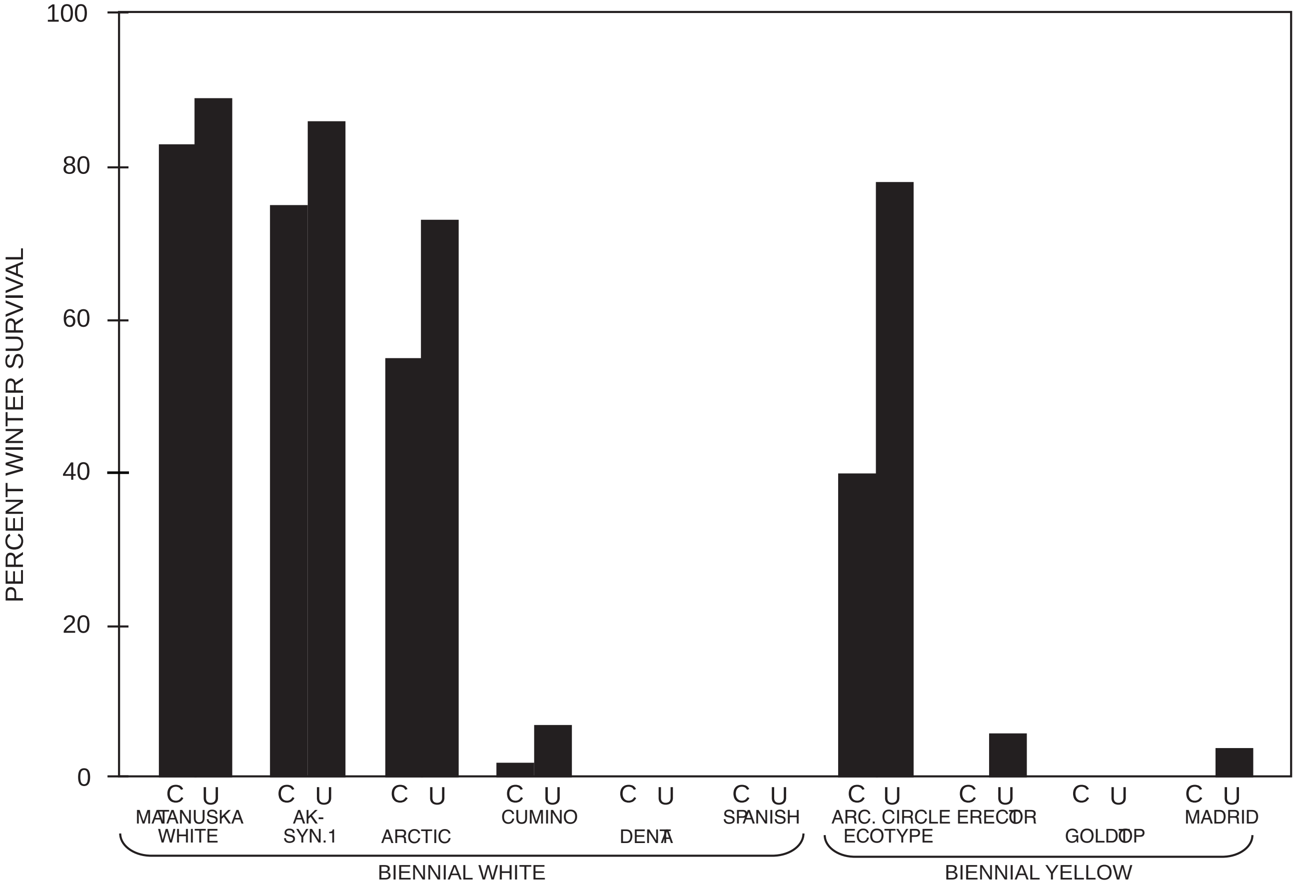


Figure 6. Percent winter survival of six biennial white and four biennial yellow sweetclover strains of diverse latitudinal adaptation, as influenced by cutting (C) for forage on 29 September of the seeding year versus uncut (U) with seeding-year growth left intact over winter. Rows seeded 9 June of the previous year (Exp. II).

tional activities contributing to food-reserve storage and winter-hardening development were completed, (b) plant stubble and crowns sustained harmful physical damage (splitting, breakage) from action of the sickle mower when topgrowth was severed, and/or (c) severed stubble permitted access to pathogens.

Badger and Snider (1933) in Illinois, Martin (1934) in Iowa, Smith and Graber (1948) in Wisconsin, and Willard (1927) in Ohio also reported poorer winter survival of biennial sweetclover harvested during the latter portion of the seeding year versus stands not harvested.

Experiment III -

Effects of Time of Harvest on Seeding-Year Forage Yields, Winter Survival, and Second-Year Forage Yields.

Seeding-year forage dry-matter yields of AK-Syn.1 sweetclover increased regularly from a very small yield at first harvest on 20 July (0.04 T/A) to 2.52 T/A at the final regular harvest on 20 September (Fig. 7). During the same period, percent crude protein in harvested forage decreased from 33.7% to 13.6% (Fig. 7).

By the end of the growing season, when all plots were trimmed to a 2-inch stubble on 6 October, regrowth that had occurred since the different seeding-year harvest dates was as follows:

Harvest date	Growth and development
20 July	Regrowth 34 to 36 inches tall
30 July	Regrowth 22 to 26 inches tall
10 Aug	Proliferation of leafy, relatively unelongated growth from 2 to 3 axils on 6-inch stubble
20 Aug	Medium abundance of leaves from 2 to 3 axils on 6-inch stubble
30 Aug	Very few leaves had appeared
10 Sep	No leaves or regrowth
20 Sep	No leaves or regrowth
Not cut	Original growth 36 to 42 inches tall

Of the three cutting dates (10 Aug., 10 Sep., 6 Oct.) sampled on 6 October to assess quantities of stored food reserves present in roots, reserves were highest where topgrowth had not been removed until the sampling date (6 October) (Fig. 8). Roots from plants that had topgrowth harvested 10 August or 10 September were much lower in stored reserves, indicating that removal of photosynthetic capabilities interfered considerably with pre-winter manufacture and storage of food reserves. A slightly lower level of reserves in roots where the topgrowth had been harvested 10 September suggests that harvest date had disadvantaged plants more than the earlier date.

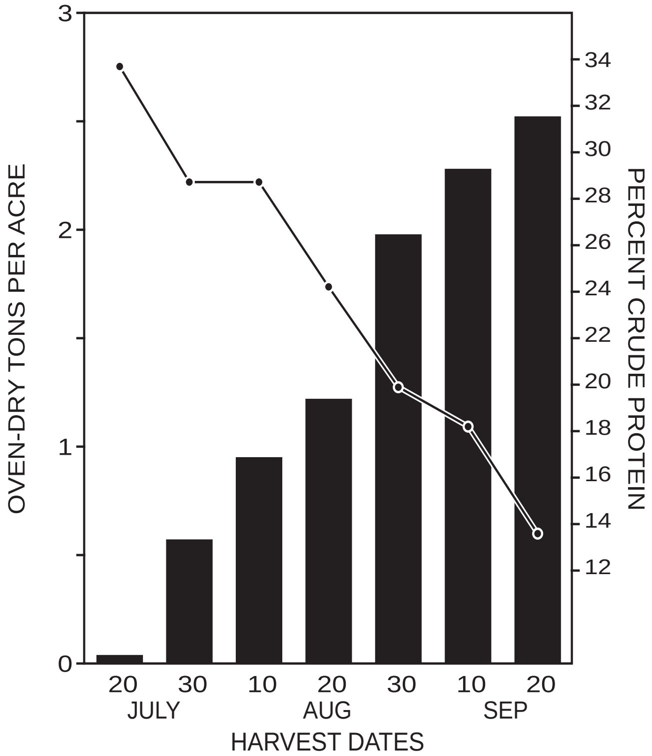


Figure 7. Seeding-year forage yields (vertical bars) and percent crude protein (connected dots) in herbage of AK-Syn.1 sweetclover as influenced by different harvest dates at the Fairbanks Experiment Farm. Plots broadcast-seeded on 8 June (Exp. III).

Estimates of plant winter survival, based on fall and spring plant counts, indicated a relatively severe stand loss in all plots over winter (Fig. 9). Although survival averaged only 29% over all treatments, best survival (40%) resulted from earliest (20 July) seeding-year harvest, and poorest (11%) with harvest on 30 August.

As plants put forth second-year growth, differences in growth and vigor were apparent among plots that had been harvested on different seeding-year dates; those differences were still obvious in July just prior to forage harvest (Fig. 10).

At the uniform evaluation harvest of all plots on 11 July of the second year (Fig. 11), forage yields ranged from 1.18 T/A from plots harvested 30 August of the previous year, to 2.83 T/A from plots not harvested until 6 October of the seeding year. Mean percent crude protein in the 11 July forage harvest was 18.8%.

A general, but somewhat imperfect match, is seen in the trends of stored food reserves (Fig. 8), winter survival (Fig. 9), and second-year height of plants and forage yields in July (Fig. 11). Plants were tallest and forage yields highest in the second year where the sweetclover had been harvested earliest or latest in the seeding year. Conversely, plants were shortest, winter survival was poorest, and second-year yields were lowest where seeding-year harvest had been on 30 August. Although only three treatments were evaluated for pre-winter levels of stored food reserves, the closest treatment in time of harvest (10 Sep.) to the most harmful harvest date (30 Aug.), was the lowest of the three in level of stored reserves.

It is apparent from these results that all seeding-year forage harvests between late July and mid-to-late September resulted in decreased second-year forage yields, and greatest suppression resulted from harvest on 30 August. It is understandable that the earliest seeding-year harvest (20 July) resulted in little harmful effect because little topgrowth was present to be removed.

Considering all of the data, seeding-year harvest in mid-to-late September should be preferred. Harvest then produced over two tons of forage dry matter per acre with a crude protein level of 12% to 15%, and caused relatively little suppression of second-year vigor and yield.

Time of first occurrence of frost that kills sweetclover foliage would be critical to this scenario, however. More experimental trials of this type should be pursued to compare weather effects in different years in both the Tanana and the Matanuska Valleys. Earlier planting dates and other winterhardy sweetclover strains should be compared as well.

Some reports of the effects of seeding-year harvest of biennial sweetclover at lower latitudes, where growing seasons terminate later, are of interest for comparison with the present results. Badger and Snider (1933) in

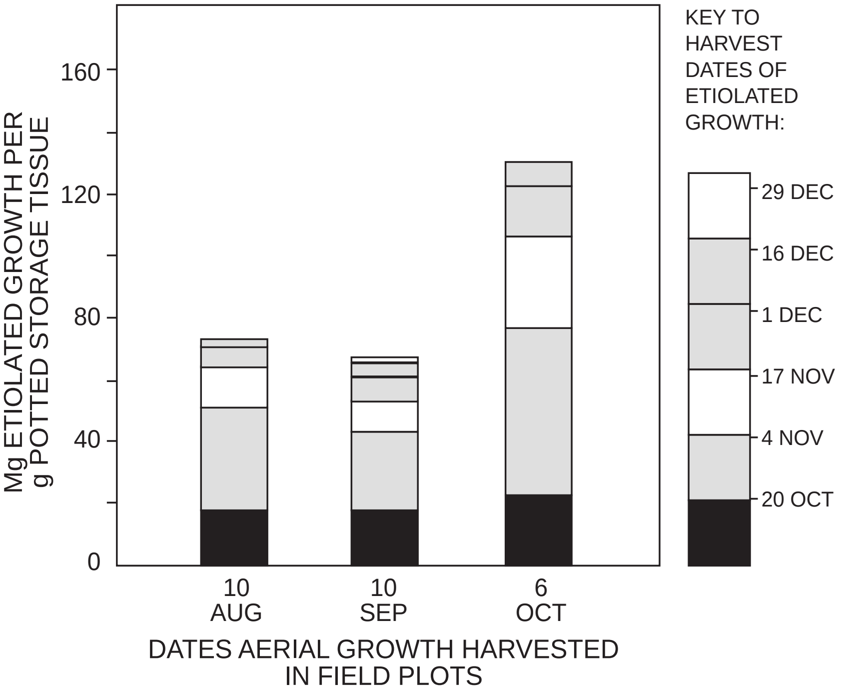


Figure 8. Stored food reserves expressed as etiolated growth from AK-Syn.1 sweetclover stem-base/crown/taproot segments and as influenced by three different dates of seeding-year forage harvest. Only three cutting treatments were selected for evaluation. Plots broadcast-seeded 8 June, plants dug from plots 6 October, Fairbanks Experiment Farm (Exp. III).

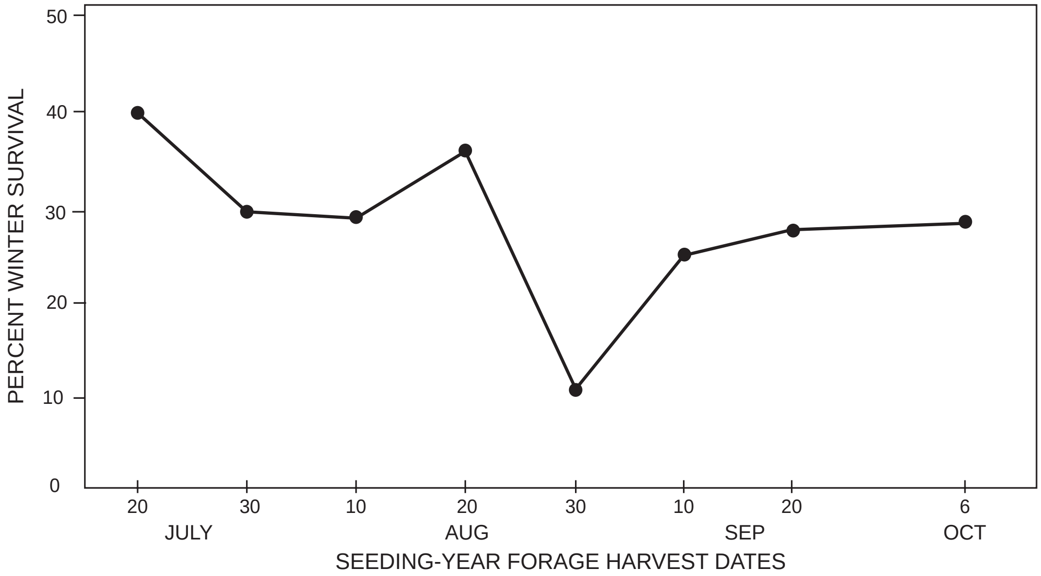


Figure 9. Percent winter survival of AK-Syn.1 sweetclover as influenced by eight different dates of seeding-year harvest at the Fairbanks Experiment Farm (Exp. III).

Illinois cited earlier reports of harmful effects of seeding-year harvests on winter survival and second-year forage yields of sweetclover. In their own work they found that seeding-year harvests on 18 September or 18 October resulted in thinned stands and lowered second-year forage yields of biennial white sweetclover, compared with stands not cut in the seeding year.

Garber *et al.* (1934) in West Virginia found that seeding-year harvests on 1 and 20 August and 10 and 30 September reduced forage yields in the second year, compared with plots not harvested the first year. However, total yields for both first- and second-year production were higher when a seeding-year harvest was taken, and total 2-year yields were relatively unaffected by the four different seeding-year harvest dates.

Willard (1927) in Ohio reported winterkill of 75%, 53%, and 12% in biennial sweetclover following seeding-year harvests on 9 September, 25 September, and 2 November, respectively, compared with only 5% winterkill where no seeding-year harvest was taken.

Smith and Graber (1948) studied in detail the effects of four seeding-year harvest dates (16 Aug., 2 Sep., 18 Sep., 18 Oct.), vs. no harvest, on two strains of biennial sweetclover in Wisconsin where growing seasons are considerably longer than in Alaska's agricultural areas. Harvest on 18 September was the most detrimental, reducing dry weight of roots, amount of readily available carbohydrates and total nitrogen in the roots, size of crown buds formed, and forage yield the following spring. All other cutting dates produced similar but less harmful effects, compared with plants unharvested during the seeding year. No differences in winter survival were reported.

The exploratory findings of Exps. II and III, and the Midwest results, suggest that additional investigations in Alaska should be informative and useful that evaluate more extensively and with hardiest sweetclover strains the effects of various seeding-year harvest dates. Different stubble heights that would provide for retention of insulating snow cover should be evaluated for the Matanuska Valley where strong winter winds occur (Dale 1956; Klebesadel 1974). Artificial provision for snow retention is not a concern in the Fairbanks area where Exp. III was conducted; strong winter winds do not occur there so snow cover generally remains in place.

In more southern areas, where seeding-year growth of biennial sweetclover is much shorter, grazing of spring-seeded stands is sometimes practiced (Fergus 1958; Hollowell 1959; Smith *et al.* 1986). Those authors emphasize that grazing plants too short can be very injurious to

Figure 10. AK-Syn.1 sweetclover seeded 8 June 1965 and photographed 11 July 1966 at the Fairbanks Experiment Farm. Tall plot to left of center was harvested 6 October 1965; shorter plot to right of center was harvested 30 August 1965. On day of photograph, left-plot treatment yielded at the rate of 2.83 tons oven-dry forage per acre, while right-plot treatment averaged only 1.18 T/acre (Exp. III).

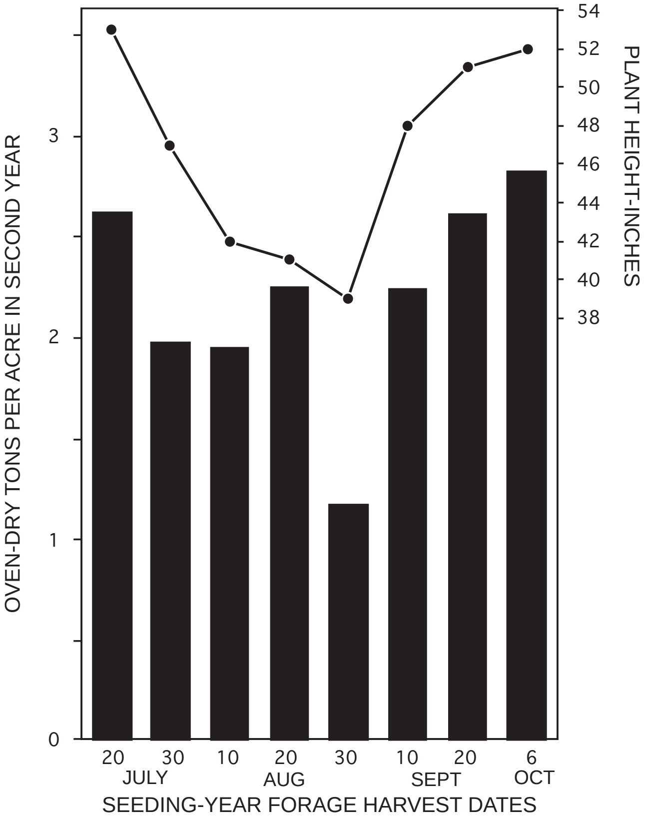


Figure 11. Second-year plant height (connected dots, measured 7 July) and forage yields (vertical bars, harvested 11 July) of AK-Syn.1 sweetclover as influenced by eight different dates of seeding-year forage harvest at the Fairbanks Experiment Farm (Exp. III).

winter survival. Several axils (branching sites) on the mainstem must be left intact for regrowth of leaves to carry on active photosynthesis; otherwise no regenerative sites for regrowth are left and plants weaken and die.

The results reported here, showing marked influences of time-of-harvest during the latter portion of the seeding-year on winter survival and second-year vigor and forage yields of sweetclover, parallel results found at this location with other forage species. Different times of seeding-year harvest predisposed both smooth bromegrass and Siberian wildrye to considerably different extents of subsequent winter survival and second-year stand health and productivity (Klebesadel 1993b, 1993c).

Experiment IV—

Influence of Two Plantings Dates on Seeding-Year Forage Yields, and on Proportions and Crude Protein Concentrations of Leaves and Stems in Herbage of 12 Strains.

On 22 August, well before the end of the growing season, most strains in the earliest-planted rows were flowering, with the annual Hubam and biennial yellow Madrid being the most advanced (Table 2). Rows planted 12 June were just beginning to flower.

In contrast to all other strains, Brandon Dwarf, a cultivar from Manitoba, and Denta, from Wisconsin, showed no flowering. Smith and Gorz (1965) describe the low-coumarin Denta as late flowering. At harvest on 21 September, most strains seeded 25 May possessed many green seed pods and Denta was then actively flowering. The short-growing Brandon Dwarf had no green seed pods on that date and still showed little evidence of flowering.

At harvest on 21 September, percent leaves was lower, and percent stems higher, in strains planted 25 May than in those planted 12 June (Table 3). Forage of the tallest-growing cultivars (see Table 2) tended to be lower in percent leaves and higher in percent stems than the shorter-growing strains.

Kirk (1926) reported 63.3% leaves in Arctic

Table 2. Seeding-year plant height and flowering of 12 sweetclover strains on 22 August and 21 September as influenced by two dates of seeding at the Matanuska Research Farm (Exp. IV).

Sweetclover strains	Visual estimates on 22 August of number of racemes in flower per row: Rows seeded 25 May	12 June	Plant height and development on 21 September: Rows seeded 25 May: Height (inches)	Amount of flowering	Green seed pods	Rows seeded 12 June: Height (inches)	Amount of flowering	Green seed pods
Biennial white:								
Matanuska white	80	6	36-38	Much	Many	18-20	Little	Some
AK-Syn.1	60	4	50-52	Much	Many	38-40	Much	Some
Arctic	80	6	52-54	Much	Many	38-40	Much	Some
Brandon Dwarf	0	0	34-36	Little	None	24-26	None	None
Cumino	120	2	44-46	Some	Some	34-36	Little	Some
Denta	0	0	50-52	Much	Many	48-50	Little	None
Spanish	120	8	54-56	Much	Many	44-46	Much	Some
Annual white:								
Hubam	300	15	72-74	Much	Many	52-54	Much	Some
Biennial yellow:								
Arctic Circle ecotype	100	0	42-44	Much	Some	34-36	Little	Some
Erector	60	20	52-54	Much	Some	36-38	Much	Some
Goldtop	120	10	52-54	Much	Many	38-40	Much	Some
Madrid	600	60	54-56	Much	Many	40-42	Much	Some

sweetclover harvested in September of the seeding year in Saskatchewan (planting date not stated). In the present study, Arctic had only 28% and 39% leaves from late May and mid-June plantings, respectively. This difference between locations is not surprising because the long summer photoperiods (short nyctoperiods) at this higher latitude induce taller seeding-year growth, resulting in a greater proportion of stems and therefore lower percentage of leaves.

The extremes in percent leaves and stems at harvest on 21 September were represented by the annual Hubam, planted 25 May, with 77% stems and 23% leaves, and the much shorter Matanuska white which had 62% leaves and only 38% stems where planted 12 June.

Crude protein concentration was much higher in leaves than in stems (Table 3). Mean percent crude protein in leaves over all strains and both planting dates was 24.0%, while the overall mean for stems was 6.8%. Over all strains, percent crude protein was slightly lower in both the stems and the leaves from the 25 May planting date than from the later (12 June) planting. For the 25 May and 12 June plantings, percent crude protein in leaves was 22.2% and 25.9%, respectively; in stems the values were 5.9% and 7.7%, respectively.

Forage yields harvested 21 September ranged from 0.66 T/A for Matanuska white seeded 12 June to 3.24 T/A for Madrid seeded 25 May (Fig. 12). Highest yields were produced by the southernmost-adapted, nonhardy biennial cultivars Denta, Spanish, Goldtop, and Madrid, and the annual Hubam.

Except for a minor difference with Erector, delaying the seeding date from 25 May to 12 June resulted in marked decreases in seeding-year forage yields. Delaying the seeding date 18 days reduced the growing period from seeding to harvest by only 15%; however, averaged over all 12 strains, the decrease in forage yield was 30%. The sharply lowered yields with mid-June planting undoubtedly is related to seedlings starting growth too late to benefit from the excellent growing conditions near the beginning of the growing season when photoperiods are long and temperatures relatively warm.

Another comparison illustrating the relationship of dry-matter production vs. growth period is the average dry-matter production per acre per day for the two different periods of growth. All strains averaged 41 lb/A/day during the 119 days from seeding on 25 May to harvest on 21 September. When the 18 generally ideal growing days of late May and early June were sacrificed by seeding on 12 June (vs. 25 May), average dry-matter production over the 101-day growing period was only 34 lb/A/day.

Experiment V—

Annual Forage Production of Madrid Sweetclover as Influenced by Three Planting Dates, and Various Row Spacings vs. Broadcast Seeding.

Annual forage yields of Madrid sweetclover were influenced both by planting dates and by planting configurations (Fig. 13). Highest yields were obtained with earliest (10 May) planting date, and lowest yields with the latest (16 June) planting.

Yield differences among the five planting configurations were greatest with earliest planting and tended to be progressively less with later planting dates. With all three planting dates, rows spaced 18 inches apart re-

Table 3. Percent leaves and stems in forage and percent crude protein in leaves and stems of 12 sweetclover strains harvested 21 September of the year of planting at the Matanuska Research Farm (Exp. IV).

	Percent				Percent crude protein in:			
	Leaves		Stems		Leaves		Stems	
Sweetclover	Planted		Planted		Planted		Planted	
strains	25 May	12 June	25 May	12 June	25 May	12 June	25 May	12 June
Biennial white:								
Matanuska white	45	62	55	38	21.3	24.9	6.2	9.2
AK-Syn.1	33	39	67	61	22.4	26.5	5.7	7.5
Arctic	28	39	72	61	23.8	26.3	6.1	8.1
Brandon Dwarf	39	49	61	51	24.7	26.6	6.9	9.1
Cumino	25	38	75	62	26.1	29.7	6.3	8.4
Denta	26	34	74	66	22.2	27.3	5.5	7.4
Spanish	29	38	71	62	23.1	27.2	5.9	7.5
Mean	32.1	42.7	67.9	57.3	23.4	26.9	6.1	8.2
Annual white:								
Hubam	23	33	77	67	21.9	27.1	5.4	7.3
Biennial yellow:								
Arctic Circle ecotype	37	48	63	52	21.3	23.2	6.1	7.7
Erector	32	36	68	64	21.6	24.8	5.8	7.1
Goldtop	28	32	72	68	18.2	23.9	5.3	6.9
Madrid	28	36	72	64	19.8	23.1	5.3	6.0
Mean:	31.3	38.0	68.7	62.0	20.2	23.8	5.6	6.9

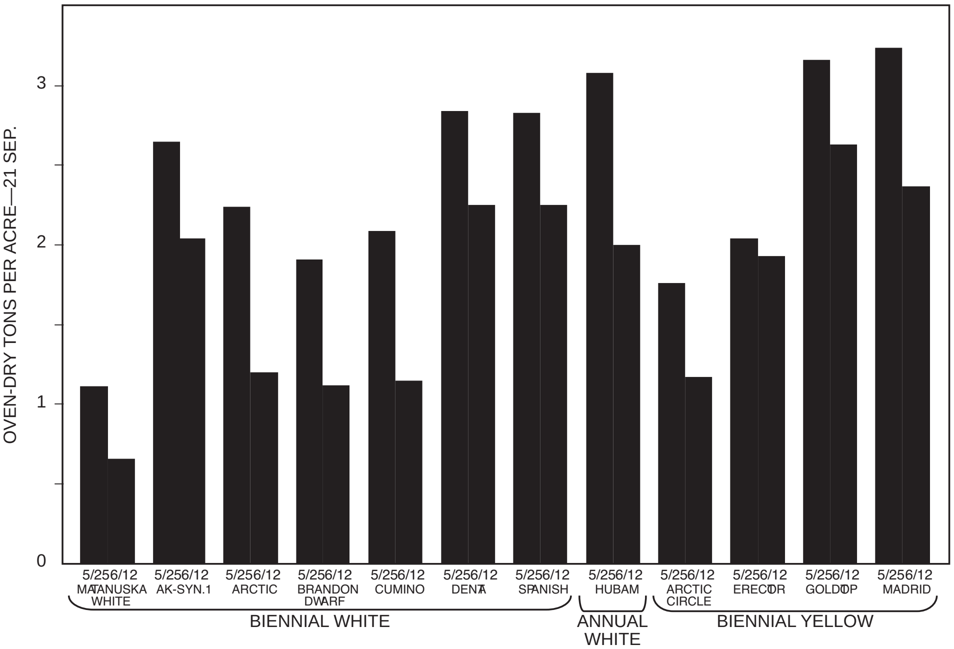


Figure 12. Seeding-year forage yields of seven biennial white, one annual white, and four biennial yellow sweetclover strains, as influenced by two dates of seeding (25 May and 12 June) in rows at the Matanuska Research Farm; harvest date was 21 September (Exp. IV).

sulted in highest yields, though differences among some row spacings were small with the two later planting dates. Broadcast seeding was generally among the lowest yielding treatments except it surpassed yields of rows 24 and 36 inches apart with the 16 June planting.

Highest seeding-year forage yields with this nonhardy, temperate-latitude-adapted sweetclover were obtained from rows planted 18 inches apart in early May.

Experiments VI, VII, and VIII—

Seeding-Year Forage Production of 11 Diversely Adapted Strains Seeded on Different Dates in Three Different Years.

The cumulative results of these three experiments, shown in Figure 14, agree with and reinforce the results of Exp. IV (2 planting dates) and Exp. V (3 planting dates) on the importance of early planting to maximize seeding-year forage yields of sweetclover at this northern latitude.

The three experiments, planted 20 May, 30 May, and 9 June, resulted in progressively lower forage yields with later planting dates. Moreover, the earliest planting date (20 May) is somewhat later than the 5 to 15 May period when weather conditions typically permit earliest planting in this area; thus, even greater yields might have been possible with planting earlier than 20 May.

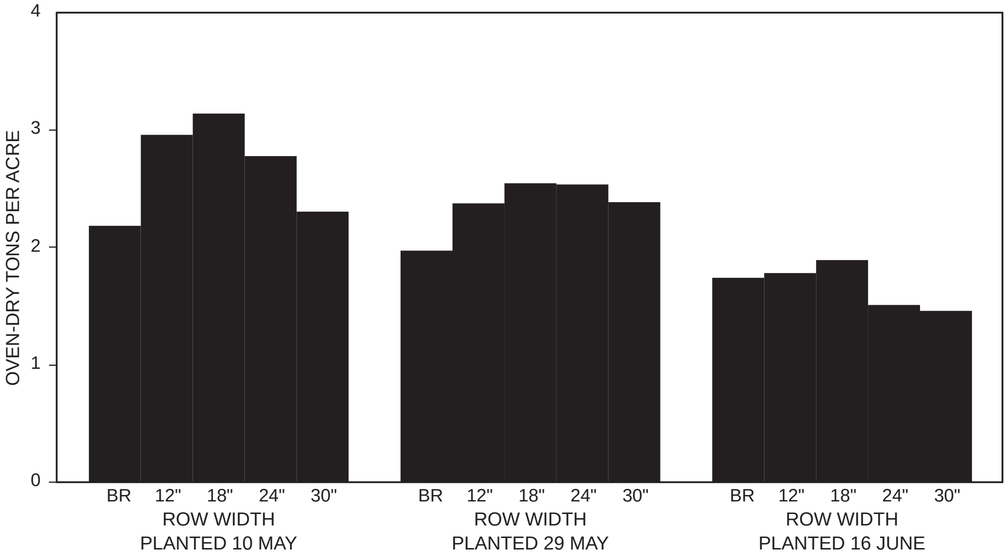


Figure 13. Seeding-year forage yields of Madrid sweetclover as influenced by three dates of planting and broadcast seeding (BR) vs. four different spacings between rows at the Matanuska Research Farm; all harvested 21 September (Exp. V).

With early seeding, the initial growth of seedlings gains maximum benefit from the generally ideal growing conditions of May and June when warm temperatures and long photoperiods prevail. Later planting results not only in a shorter growing period before harvest (near the end of the growing season) but a greater proportion of that shorter growing period occurs during the less favorable growing conditions of progressively shorter photoperiods and cooler temperatures that characterize the latter portion of the growing season.

Although Exp. VI received somewhat more precipitation than Exps. VII and VIII (Fig. 14), it also benefited from a considerably longer growth period (141 days) from planting to harvest than the latter two experiments that had only 132 and 112 days, respectively. Averaging forage yields of the seven strains included in all three experiments, and equating that production with the respective growing periods from planting to harvest in Exps. VI, VII, and VIII, the three tests resulted in 46, 34, and 20 pounds of oven-dry forage produced per acre per day.

These three experiments also illustrate again the

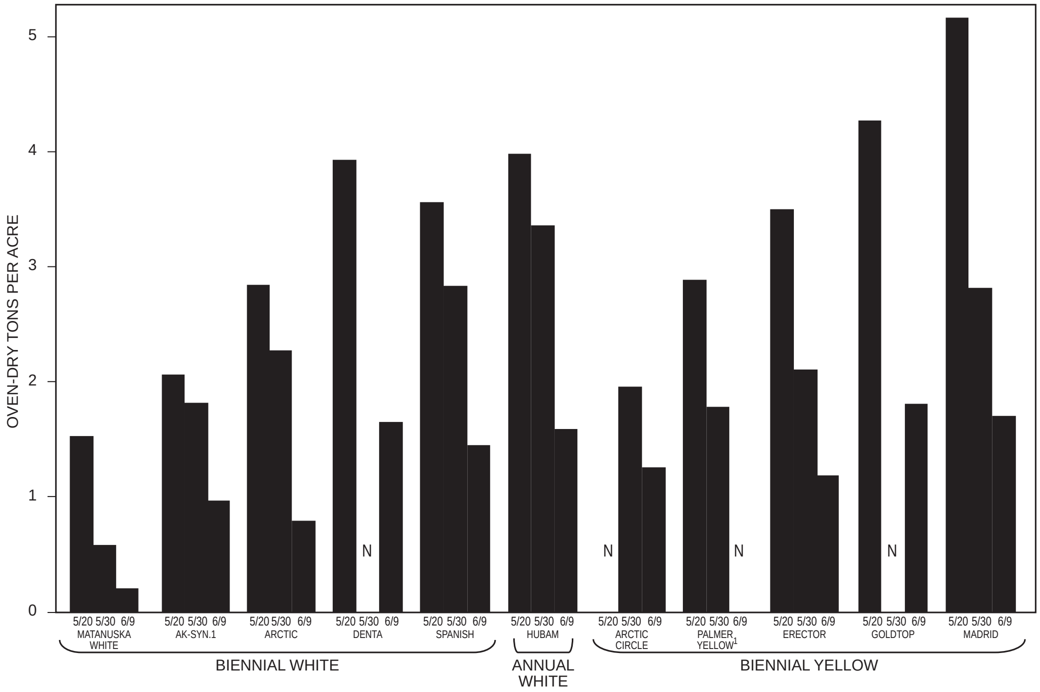


Figure 14. Seeding-year forage yields of five biennial white, one annual white, and five biennial yellow sweetclover strains seeded in rows in three experiments in three different years and differing considerably in planting dates. Planting dates are indicated at base of graph bars. (N) indicates not included in experiment.

Experiment	Date planted	Date harvested	Days from planting to harvest	Pounds dry matter produced per acre per day from seeding to harvest[2]	April through Sep. precipitation departure from normal (inches)
VI	20 May 1963	8 Oct	141	46	+0.24
VII	30 May 1964	9 Oct	132	34	-1.28
VIII	9 June 1966	29 Sep	112	20	-0.59

[1] For background on 'Palmer yellow' strain, see Alaska Agric. and Forestry Exp. Sta. Bull. 91 (Klebesadel 1992b).
[2] Calculated using only the 7 strains used in all 3 experiments.

superior annual forage productivity of Hubam annual sweetclover and the most southern-adapted biennial cultivars (Spanish, Denta, Madrid, Goldtop) over the more winterhardy and more northern-adapted strains (AK-Syn.1, Matanuska white, Arctic Circle strain). The intermediate-latitude (and intermediately winterhardy) cultivars Arctic and Erector from Canada were intermediate in forage yield.

CONCLUSIONS

Seeding-year growth of biennial sweetclovers at this high subarctic latitude differs considerably from normal developmental behavior of the crop at mid-temperate latitudes where those species originated and traditionally have been grown. At those more southern latitudes, seeding-year sweetclover topgrowth achieves a modest height on small-diameter stems, does not flower, and in late-summer / autumn produces many, large crown buds on a greatly enlarged taproot. Those pre-winter morphological characteristics are accompanied by physiological winter-hardening adequate to confer good winter survival when those strains are grown where they are well adapted.

In contrast, when biennial sweetclovers are grown in Alaska and seeded early without a companion crop, the unique summer photoclimate of this area (long photoperiods / short nyctoperiods) induces tall growth on large-diameter mainstems, profuse flowering, and minimal development of few and small crown buds on a modestly enlarged taproot. These growth characteristics resembling annual sweetclover are followed by generally inadequate winter-hardening, leading to marginal to poor winter survival.

The winter survival in Alaska of biennial sweetclovers from more southern latitudes is influenced considerably by the latitude at which strains are adapted. For example, the cultivars Spanish and Madrid that originated in Spain (ca. 36° to 44°N) seldom survive winters in Alaska. The more northern-adapted cultivar Arctic (selected at 52°N in Canada from stock that originated at about 50° to 51°N in Russia and has been perpetuated at relatively northern latitudes in Canada) is much superior to Spanish and Madrid, though often marginal, in winter survival here.

Three strains developed through natural selection in Alaska demonstrate that considerable improvement toward better adaptation and winter survival in Alaska has been achieved, suggesting therefore that more improvement should be possible through intensified efforts. This progress in improved winterhardiness infers that biennial sweetclover may become a useful and valuable legume in Alaska agriculture.

However, results presented in this report generally argue against attempting to utilize biennial sweetclover for forage in both the seeding year and in the second year of growth. Winter survival of even the most winterhardy strains in the stressful field environment is marginal with no forage harvest of seeding-year growth, and becomes much less so when a seeding-year harvest is taken. Despite some dates of seeding-year harvest being less damaging to winter survival and second-year yield than others, even the most favorable time of harvest predisposed the crop to generally poor survival.

Therefore, it appears that in Alaska sweetclover should be grown either as an annual crop, or for forage in the second year of growth. Those two approaches necessarily require very different types of sweetclover strains, each ideally suited to fulfilling very different grower objectives.

For annual production of forage, the most productive annual or nonhardy biennial strains should be grown, the latter with no concern for winter survival. Prudent choices for Alaska growers should include:

(a) use relatively southern-adapted biennial (or annual) strains that are very leafy, tall-growing, and therefore productive of high yields of high-quality forage,
(b) plant low-coumarin strains to avoid possibilities of dicoumarol-induced feeding problems from spoiled hay or silage,
(c) plant as early as possible,
(d) plant in rows about 18 inches apart, and
(e) follow procedures detailed below under the heading "Management Concerns Not Studied But Important to Growers."

The above procedures can be pursued at present using commercially available seed supplies. The following procedures, for second-year forage production, require strains possessing winterhardiness levels superior to strains now available commercially. Therefore, reasonable assurance of successful second-year forage production must await release of subarctic-adapted cultivars and increase of seed of those strains.

To grow the most winterhardy biennial sweetclover strains for forage production in their second year of growth, the preferred procedure in this area should be to establish the sweetclover with a cereal companion crop (as has been done experimentally in other work at this location but not reported here). By this technique, the cereal crop provides a forage crop during the year that the sweetclover seedlings are becoming established as described in the next section.

Establishing Sweetclover with a Cereal Companion Crop

Experiments reported here dealt only with sweetclover seeded alone and did not explore or evaluate the alternative procedure of establishing biennial sweetclover as an "underseeding" in association with a small-grain companion crop (Hollowell 1959). In Alaska the choices of cereal companion crop should be oats or awnless barley harvested at an immature stage for forage. By that technique, both the cereal crop and the sweetclover are seeded at the same time but by separate methods that place the sweetclover at a much shallower (⅛" to ½") depth than the deeper-sown cereal crop.

The cereal companion crop helps to suppress weed growth and also provides a forage-crop return from the land during the year that the sweetclover becomes established. However, the very competitive cereal crop also greatly suppresses the size and vigor of the sweetclover seedlings and the sweetclover therefore supplies no forage yield during the year of establishment.

Lodging of the companion crop is a hazard that can smother the legume seedlings. Therefore, removing the cereal companion crop at an immature stage for forage (rather than at maturity for grain and straw) not only lessens the danger of harmful lodging but affords the sweetclover seedlings a longer period for unimpeded growth between the time of companion-crop harvest and termination of the growing season. The companion crop sowing rate should be reduced somewhat from rates normally used in growing a grain crop to maturity; a lower seeding rate helps to lessen shading and other competitive effects that suppress growth of sweetclover seedlings.

When sweetclover is established with a cereal companion crop, harvest equipment should be adjusted to leave a tall (8- to 10-inch) companion-crop stubble. That elevated cutting height leaves much of the sweetclover seedling growth intact for continued growth. Also critically important, that tall stubble can be very effective in retaining snow cover in place against the evacuation force of strong winter winds that commonly occur in the Matanuska Valley (Klebesadel 1974). Insulation provided by the snow cover protects overwintering legume seedlings from direct exposure to low or oscillating (thawing and refreezing) air temperatures, resulting in vastly improved winter survival (Klebesadel 1992a).

If seeded with a cereal companion crop, broadcast seeding of the sweetclover may be preferable to seeding in rows for best survival and spring growth. It has been noted that with spring drying of Knik silt loam, soil shrinkage commonly leads to cracking and parting of the soil along rows of plants. This leads to unfavorable exposure and dehydration of sweetclover roots and soil surrounding them; the random placement of plants in broadcast-seeded stands minimizes this undesirable effect.

Management Concerns Not Studied but Important to Growers

Several cultural and management practices that are basic to establishment of sweetclover and other small-seeded forage crops were not studied as variables in these experiments but were nonetheless employed as basic procedures vital to successful culture of this crop; they are important both in experiments and in farm-scale operations.

Those practices include plowing to prepare good seedbeds, incorporation of adequate rates of the major fertilizer nutrients into the seedbed, rapid completion of all tillage and planting practices to conserve soil moisture, shallow placement of seed in the top 1/2 inch of soil, and immediate compaction of the seedbed. Failure to follow these practices can result in poor stand establishment. Appropriate *Rhizobium* bacterial inoculant should be mixed with sweetclover seed just prior to planting and fresh inoculant should be used to ensure viability of the bacteria.

Another critical requirement is effective control of weeds, especially during early sweetclover seedling growth when rapidly growing annual weeds can overwhelm the forage seedlings. Use of effective weed-control measures, including safe, approved herbicides is important to realizing the production potentials of sweetclover in farm practice as well.

The Future

The management studies reported here represent chiefly exploratory investigations, yielding preliminary and tentative results. The reported results can, nonetheless, serve on an interim basis for recommendations on sweetclover management until future, more extensive studies are completed. These results and other findings concerning sweetclover performance, improvement, and management in Alaska (Hodgson and Bula 1956; Klebesadel 1992b, 1992c, 1993a), suggest certain avenues for future work with this crop, both for annual and biennial forage production.

Expanded studies can broaden our presently modest informational base and define management practices that will permit successful incorporation of sweetclover into forage production systems in Alaska. Research directions that should be informative and worthwhile include the following:

(a) The relatively rapid progress already achieved at this location in selective genetic modification toward improved subarctic adaptation and superior winterhardiness in both biennial species infers that further progress should be possible. If pursued, future efforts should result in even better adapted, more winterhardy strains than the experimental ones currently available. Development of adapted cultivars, followed by increase of commercial quantities of seed, will afford growers the option of incorporating biennial sweetclover into forage-production programs.

(b) Early planting of relatively southern-adapted, nonhardy, low-coumarin strains that are now commercially available can provide high yields of high-protein annual forage. This forage ensiled alone, or in combination with various ratios of oats or awnless barley, should be evaluated in feeding trials.

(c) The northernmost-adapted, low-coumarin cultivars developed elsewhere could be incorporated into acclimatization efforts to determine the extent to which selection could be achieved toward adapted, winterhardy strains free of potentially harmful coumarin levels for use in Alaska.

Acknowledgments

I thank Darel Smith and Franz Maier for technical assistance with these experiments, Vivian Burton for Kjeldahl N analyses, Bobbi Kunkel and Peg Banks for manuscript typing, Keith Swarner for compositing and graphic contributions, and Stephen Lay for editorial oversight. These experiments were conducted in cooperation with the Agricultural Research Service, U.S. Department of Agriculture.

Literature Cited

Arakeri, H.R., and A.R. Schmid. 1949. Cold resistance of various legumes and grasses in early stages of growth. Agronomy Jour. 41:182-185.

Badger, C.J., and H.J. Snider. 1933. The composition of the spring growth of sweet clover as influenced by previous fall treatment. Jour. American Soc. Agronomy 25:105-108.

Bula, R.J., and Dale Smith. 1954. Cold resistance and chemical composition in overwintering alfalfa, red clover, and sweetclover. Agronomy Jour. 46:397-401.

Dale, R.F. 1956. The climate of the Matanuska Valley. U.S. Dep. Commerce Weather Bureau Tech. Paper 27. U.S. Government Printing Office, Washington, DC.

Fergus, E.N. 1958. Sweet clover in Kentucky. Kentucky Agric. Extension Serv. Circ. 366-A.

Garber, R.J., M.M. Hoover, and L.S. Bennett. 1934. The effect upon yield of cutting sweet clover (*Melilotus alba*) at different times and at different heights. Jour. American Soc. Agronomy 26:974-977.

Goplen, B.P. 1971. Yukon sweetclover. Canadian Jour. Plant Science 51:178-179.

Goplen, B.P., and A.T.H. Gross. 1977. Sweetclover production in western Canada. Agriculture Canada Pub. 1613.

Graham, E.H. 1941. Legumes for erosion control and wildlife. U.S. Dep. Agric. Misc. Pub. 412. U.S. Government Printing Office, Washington, DC.

Hansen, H.C. 1927. Plant introductions. South Dakota Agric. Exp. Sta. Bull. 224.

Hodgson, H.J., and R.J. Bula. 1956. Hardening behavior of sweetclover (*Melilotus* spp.) varieties in a subarctic environment. Agronomy Jour. 48:157-160.

Hollowell, E.A. 1959. Sweetclover. U.S. Dep. Agric. Leaflet 23. U.S. Government Printing Office, Washington, DC.

Kasperbauer, M.J., F.P. Gardner, and W.E. Loomis. 1962. Interaction of photoperiod and vernalization in flowering of sweet clover (*Melilotus*). Plant Physiology 37:165-170.

Kasperbauer, M.J., H.A. Borthwick, and H.M. Cathey. 1963a. Cyclic lighting for promotion of flowering of sweetclover, (*Melilotus alba* Desr.). Crop Science 3:230-232.

Kasperbauer, M.J., F.P. Gardner, and I.J. Johnson. 1963b. Taproot growth and crown bud development in biennial sweetclover as related to photoperiod and temperature. Crop Science 3:4-7.

Kirk, L.E. 1926. A comparison of sweet clover types with respect to coumarin content, nutritive value, and leaf percentage. Jour. American Soc. Agronomy 18:385-392.

Klebesadel, L.J. 1969a. Life cycles of field pennycress in the Subarctic as influenced by time of seed germination. Weed Science 17:563-566.

Klebesadel, L.J. 1969b. Winter survival and spring forage yield of winter rye varieties in subarctic Alaska as influenced by date of planting. Agronomy Jour. 61:708-712.

Klebesadel, L.J. 1970. Influence of planting date and latitudinal provenance on winter survival, heading, and seed production of bromegrass and timothy in the Subarctic. Crop Science 10:594-598.

Klebesadel, L.J. 1971. Selective modification of alfalfa toward acclimatization in a subarctic area of severe winter stress. Crop Science 11:609-614.

Klebesadel, L.J. 1974. Winter stresses affecting overwintering crops in the Matanuska Valley. Agroborealis 6(1):17-20.

Klebesadel, L.J. 1980. Birdvetch: Forage crop, ground cover, ornamental, or weed? Agroborealis 12(1):46-49.

Klebesadel, L.J. 1985a. Adaptational changes induced in temperate-adapted forage legumes by natural selection pressures in subarctic Alaska. p. 304-315. *In*: A. Kaurin, O. Junttila, and J. Nilsen (eds.). Plant Production in the North. Proceedings, International Symposium on Plant Adaptation to Northern Conditions. Sep. 1983. Tromsø, Norway. Norwegian University Press, Oslo, Norway.

Klebesadel, L.J. 1985b. The critical importance of north-latitude adaptation for dependable winter survival of perennial plants in Alaska. Agroborealis 17(1):21-30.

Klebesadel, L.J. 1986. Natural selection may modify introduced white clover toward superior winterhardiness. Agroborealis 18(1):13-19.

Klebesadel, L.J. 1992a. Effects of planting date and latitude-of-adaptation on seeding-year development, winter survival, and subsequent seed and forage production potential of grasses and legumes in subarctic Alaska. Alaska Agric. and Forestry Exp. Sta. Bull. 86.

Klebesadel, L.J. 1992b. Morphological, physiological, and winterhardiness comparisons among latitudinal ecotypes of biennial sweetclover (*Melilotus* species) in subarctic Alaska. Alaska Agric. and Forestry Exp. Sta. Bull. 91.

Klebesadel, L.J. 1992c. Extreme northern acclimatization in biennial yellow sweetclover (*Melilotus officinalis*) at the Arctic Circle. Alaska Agric. and Forestry Exp. Sta. Bull. 89.

Klebesadel, L.J. 1993a. Effects of daily photoperiod/ nyctoperiod and temperature on autumn development of crown buds and dormancy, freeze tolerance, and storage of food reserves in latitudinal ecotypes of biennial white sweetclover. Alaska Agric. and Forestry Exp. Sta. Bull. 95.

Klebesadel, L.J. 1993b. Bromegrass in Alaska. III. Effects of planting dates, and time of seeding-year harvest, on seeding-year forage yields and quality, winter survival, and second-year spring forage yield. Alaska Agric. and Forestry Exp. Sta. Bull. 96.

Klebesadel, L.J. 1993c. Winterhardiness and agronomic performance of wildryes (*Elymus* species) compared with other grasses in Alaska, and responses of Siberian wildrye to management practices. Alaska Agric. and Forestry Exp. Sta. Bull. 97.

Klebesadel, L.J. 1993d. Winter survival of grasses and legumes in subarctic Alaska as related to latitudinal adaptation, pre-winter storage of food reserves, and dry-matter concentration in overwintering tissues. Alaska Agric. and Forestry Exp. Sta. Bull. 94.

Martin, J.N. 1934. The relative growth rates and interdependence of tops and roots of biennial white sweet clover, *Melilotus alba* Desr. American Jour. Botany 21:140-159.

Ouellet, C.E. 1976. Winter hardiness and survival of forage crops in Canada. Canadian Jour. Plant Science 56:679-689.

Smith, Dale. 1957. Flowering response and winter survival in seedling stands of red clover. Agronomy Jour. 49:126-129.

Smith, Dale. 1963. Reliability of flowering as an indicator of winter survival in red clover. Canadian Jour. Plant Science 43:386-389.

Smith, Dale, and L.F. Graber. 1948. The influence of top growth removal on the root and vegetative development of biennial sweetclover. Jour. American Soc. Agronomy 40:818-831.

Smith, Dale, R.J. Bula, and R.P. Walgenbach. 1986. Sweetclover characteristics and management. p. 139-146. (In) Forage management (5th ed.) Kendall/ Hunt Pub. Co., Dubuque, IA.

Smith, T.J. 1942. Responses of biennial sweet clover to moisture, temperature, and length of day. Jour. American Soc. Agronomy 34:865-876.

Smith, W.K., and H.J. Gorz. 1965. Sweetclover improvement. Advances in Agronomy 17:163-231.

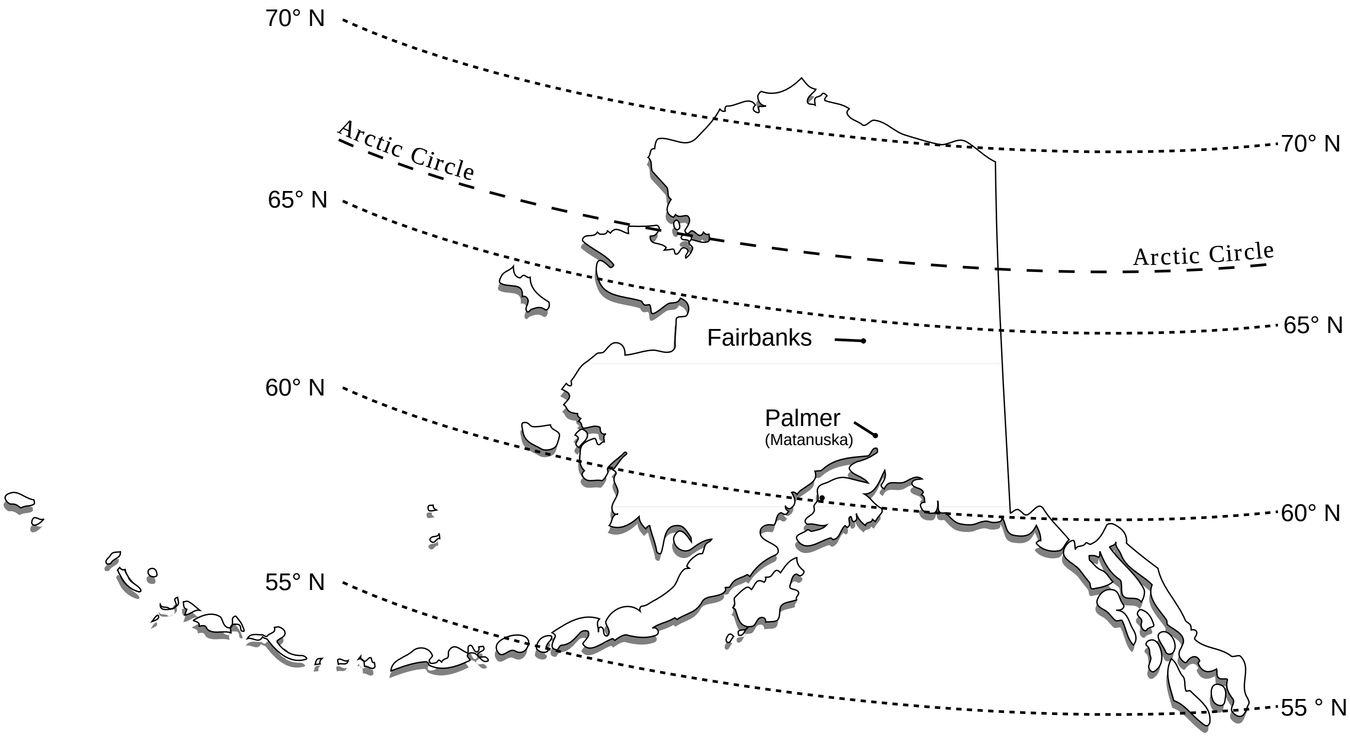
Therrien, H.P., and Dale Smith. 1960. The association of flowering habit and winter survival in red and alsike clover during the seedling year of growth. Canadian Jour. Plant Science 40:335-344.

White, W.J., and W.H. Horner. 1943. The winter survival of grass and legume plants in fall sown plots. Scientific Agric. 23:399-408.

Wiggans, S.C. 1953. The relationship of photoperiod to growth and flowering of *Melilotus* species. Iowa Academy of Science Proceedings 60:278-284.

Willard, C.J. 1927. Sweetclover: The effect of cutting the first year on the value for pasture and soil improvement the next year. Ohio Agric. Exp. Sta. Bimonthly Bull. 12:107-114.

Wilsie, C.P. 1962. The ecotype concept. p. 66-86. (Chapter in) Crop adaptation and distribution. W.H. Freeman and Co., San Francisco, CA.



Agricultural and Forestry Experiment Station
School of Agriculture and Land Resources Management
University of Alaska Fairbanks

♻ *Printed on recycled paper*
by UAF Printing Services