Growth, development, and composition of temperate forage legumes and grasses in varying environments

Christer Ohlsson
Iowa State University

Follow this and additional works at: https://lib.dr.iastate.edu/rtd
Part of the Agricultural Science Commons, Agriculture Commons, and the Agronomy and Crop Sciences Commons

Recommended Citation
Ohlsson, Christer, "Growth, development, and composition of temperate forage legumes and grasses in varying environments " (1991). Retrospective Theses and Dissertations. 9563.
https://lib.dr.iastate.edu/rtd/9563

This Dissertation is brought to you for free and open access by the Iowa State University Capstones, Theses and Dissertations at Iowa State University Digital Repository. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
Growth, development, and composition of temperate forage legumes and grasses in varying environments

Ohlsson, Christer, Ph.D.

Iowa State University, 1991
NOTE TO USERS

THE ORIGINAL DOCUMENT RECEIVED BY U.M.I. CONTAINED PAGES WITH BLACK MARKS. PAGES WERE FILMED AS RECEIVED.

THIS REPRODUCTION IS THE BEST AVAILABLE COPY.
Growth, development, and composition of temperate forage legumes and grasses in varying environments

by

Christer Ohlsson

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Department: Agronomy
Major: Crop Production and Physiology

Approved:

Signature was redacted for privacy.

In Charge of Major Work:

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa
1991
RESULTS AND DISCUSSION ................................................. 41

Red Clover - Growth Chamber ........................................ 41
Morphological characteristics .................................... 41
Growth characteristics ............................................. 62
Quality characteristics ........................................... 83

Timothy - Growth Chamber ......................................... 93
Morphological characteristics .................................... 93
Growth characteristics ............................................. 104
Quality characteristics ........................................... 114

Alfalfa - Field Study .................................................. 121
Location effects ...................................................... 121
Cultivar effects ....................................................... 128

Red Clover - Field Study ............................................. 137
Location effects ...................................................... 137
Cultivar effects .................................................. 148
Timothy - Field Study ......................................... 161
Location effects ............................................... 161
Cultivar effects ............................................... 173
Smooth Bromegrass - Field Study ......................... 184
Location effects ............................................... 184
Cultivar effects ............................................... 194
Implications of Results ...................................... 205

SUMMARY ....................................................... 206
Growth Chamber Study ....................................... 206
Field Study .................................................... 212

CONCLUSIONS .................................................. 215

LITERATURE CITED ............................................. 216

ACKNOWLEDGEMENTS .......................................... 227

APPENDIX ........................................................ 229
INTRODUCTION

The growing economic pressure and legislation for more environmentally sound agricultural practices have created a greater interest in using forage grasses and legumes in the temperate areas of both Scandinavia and midwestern USA. In both environments, land with moderate to steep slopes and high soil erosion presently in grain crop production is better suited for forage production because perennial forages require less tillage. Forages also produce shallow, but extensive, root systems that bind the soil and reduce nutrient leaching.

Forage crops have a potential to be better utilized for milk, meat, and wool in ruminant animal production, which presently relies heavily on grain as a feed source. To use forages more effectively and intensively as a feed source in animal production, they must be managed in such a way that energy and protein concentrations are as high as possible. Therefore, there is a need to study environmental effects of quality and composition on genetically diverse forage legumes and grasses.

The early season phenological development and compositional changes in perennial grasses and legumes are mainly related to weather conditions, fertilization, available soil water, and choice of cultivar. Scandinavia and midwestern USA offer a range of these conditions.

Dry weight of plants increase with extended daylengths as a result of increased photosynthetic energy. Plant parts are differentially affected, however. Shoot:root ratios generally increase and leaf:stem ratios generally decrease as daylengths are extended. Increased daylengths hasten maturity and increase structural components of the plant. Increased temperatures, within optimum ranges, have similar stimulatory effects on growth. Temperatures outside optimum ranges are known to cause increased leaf:stem ratios, however. The effect of soil
water on plant growth is difficult to evaluate in field experiments because water stress is often confounded with high temperatures.

Forage quality, characteristics that make a forage valuable as a nutritional source to animals, decline as a result of advanced maturity. The decline is attributed to increased concentrations of cellulose, hemicellulose, and lignin, and nutrient dilution as a result of increased growth. In spring, increased temperature affects digestibility more negatively than extended daylength (Thorvaldsson and Fagerberg, 1988). In fact, no clear direct effect of daylength on digestibility has been found (Allinson, 1971), although daylength indirectly promotes growth of stem, which is less digestible than leaf. Crude protein concentrations of forages decline with age. Conflicting reports exist, however, concerning the temperature effect on protein concentrations. Marten (1970) found that increased temperatures reduced crude protein concentrations of alfalfa, whereas Smith (1970) reported that concentrations increased in timothy and smooth bromegrass. Daylength extensions promote growth and, therefore, crude protein concentrations often become diluted.

Growth and quality is differentially affected by daylength and temperature in cultivars of temperate forage species. Northern adapted cultivars are characterized by having rapid development, a short life cycle, high critical photoperiods, and large roots to ensure sufficient storage of carbohydrate for survival during long and harsh winters. These adaptations are at the expense of vigor, and growth of herbage compared with southern adapted cultivars. Despite rapid growth and high degree of steminess, northern forage cultivars generally have higher forage quality compared with southern adapted cultivars at comparable growth stages. This has been shown by Deinum et al. (1981) working on forage grasses in northern Europe. They suggested that lignification of timothy may not keep pace with stem development at higher latitudes, thus resulting in higher digestibility despite steminess. Because their research included only one adapted cultivar of
timothy at each latitude, it was not possible to determine if this was an
environmental or a genetic effect. Thus, there is a need to further evaluate
northern forage cultivars grown south of their region of origin because of the high
forage quality potential.

Despite the knowledge of differential response in growth and quality of
northern- and southern-adapted forage cultivars, few researchers have attempted
to compare them under similar field conditions. Furthermore, few researchers have
evaluated the effects of daylength and temperature on growth and quality of forage
legumes.

The objectives of these studies were 1) to determine response in a)
morphology, b) plant mass, and c) forage quality characteristics of two genetically
diverse cultivars in each of red clover (Trifolium pratense L.) and timothy (Phleum
pratense L.) to variation in daylength and temperature under controlled growth
chamber environments; and 2) to evaluate changes in maturity and forage quality
of two genetically diverse cultivars (American and Swedish) in each of alfalfa
(Medicago sativa L.), red clover, timothy, and smooth bromegrass (Bromus
inermis Leyss.) at four different field environments.
REVIEW OF LITERATURE

General Background

Weather characteristics of Scandinavia and Midwestern USA

The climatic conditions are unique in northern Scandinavia. Annual mean temperatures are higher there than in any other region at comparable latitudes (Lomakka, 1958) because the Gulf Stream carries warm water along the Norwegian coast (Reid et al., 1959). Compared with weather conditions in Midwestern USA, the growing season is shorter, daily mean temperatures are lower, mean rainfall is lower, and daylengths are longer. Furthermore, night temperatures are lower in Scandinavia than in the Midwestern USA and rainfall in Scandinavia is more evenly distributed throughout the growing season.

On a yearly basis, solar radiation is higher at lower latitudes than at higher latitudes, especially on cloudless days (Haverkort, 1990). However, solar radiation increases more than the extension of daylight at higher latitudes (Haverkort, 1990). This fact may account for the relative increases in amount of dry matter produced from northern ecotypes of forage crops in first cut with increasing latitude of origin (Foss, 1968; Klebesadel and Helm, 1986). When these factors are considered, it is no surprise that the growth habit of forage crops differs between those grown in Scandinavia and in Midwestern USA.

Growth characteristics at different latitudes

During migration of species from lower to higher latitudes, natural selection has mainly operated on shortening the vegetative growth cycle, and increasing the survival rate through assimilate distribution to roots (Rognli, 1988).

At higher latitudes, low temperatures are the single most important factor limiting plant growth (Rognli, 1988). Plants have adapted to the cold and long day
conditions by having relatively large root or rhizome systems to ensure sufficient storage of carbohydrates and nutrient uptake before onset of winter dormancy (Billings, 1974). Large root systems, however, often are produced at the expense of top growth (Passioura, 1983).

Plants grown at northern latitudes have high growth rates (Heide, 1985; Solhaug, 1985) to ensure that plants reach reproductive development before the end of the growing season (Håbjörg, 1979; Heide, 1980, 1982). The price of reproductive success and survival at higher latitudes, however, is loss of vigor. Thus, these plants are not the most suitable for herbage production (Rognli, 1988).

What can be done to improve herbage production at northern latitudes? First, it is important to have an understanding of plant responses when plants are grown in an unadapted environment. Studies have shown that plants adapted to southern latitudes have accelerated flowering and improved regrowth when they are moved from short to long days, whereas winter survival is weakened (Pulli, 1988). These are not entirely undesirable characteristics if forage producers are interested in a high annual dry matter production and if they are willing to reestablish stands every year. Conversely, when a northern cultivar is moved south, flowering is delayed, regrowth is slowed, but overwintering is improved (Pulli, 1988). These characteristics may not be entirely undesirable either, if the producer is more interested in obtaining forage of high quality rather than high dry matter production since quality generally decreases with advanced stage of maturity. Furthermore, survival of stands is likely to be improved. A third approach is also available by crossing cultivars of southern origin with cultivars of northern origin (Rognli, 1988). However, Julén (1977) pointed out that winter survival and regrowth ability probably cannot be combined because both factors are controlled by daylength.
Winter survival

Irradiance and temperature play a key role in hardening of perennial plants (Eagles, 1989; Klebesadel, 1985; Sharratt et al., 1986; Tysdal, 1933). Apparently there is an interaction between daylength and temperature such that at high temperatures daylength may have a larger influence than temperature, whereas at lower temperatures daylength becomes less important (Klebesadel, 1985; Tysdal, 1933). Thus, it may be agronomically desirable to have daylength-sensitive plants with respect to hardening under conditions at which the change from summer to winter occurs rapidly. Under conditions where winters are less severe, it may be more desirable to have plants that are more sensitive to temperature changes to ensure active growth and a high annual forage production (Eagles, 1989).

Red clover

The genus *Trifolium* includes approximately 250 annual and perennial species that are native to the eastern Mediterranean region (Bowley et al., 1984; Cooper, 1965; Evans, 1976). Red clover is the most widely grown of all true clovers. It is adapted to a range of environmental conditions, and it is capable of producing up to 19 tonnes ha\(^{-1}\) year\(^{-1}\) of dry matter. It constitutes the second most important legume crop in USA, behind alfalfa (Ohlsson and Wedin, 1989; Taylor, 1985). In Scandinavia, the major breeding efforts among forage legumes are placed on red clover (Julén, 1977).

Red clover is a short-lived perennial, which grows most vigorously during the establishment year and in the subsequent first production year (Barnhart, 1986). Growth occurs at a temperature range between 7 and 38 °C, although optimum growth is between 20 and 25 °C, and at a pH of 6.0 to 7.5 (Bowley et al., 1984). Red clover has strong seedling vigor and shade tolerance (Bowley et al., 1984; Pulli, 1988). Red clover phases into summer dormancy if soil water is not sufficient (Pulli, 1988).
There are three red clover types: early, medium-late, and late (Pulli, 1988; Taylor, 1985). The early red clover is commonly grown in the Mediterranean region and the late red clover, also known as Mammoth, is grown in northern regions of North America and in northern Scandinavia (Taylor, 1985). The medium-late red clover, which is the most common red clover in North America and in Scandinavia, is grown between 50 and 60 °N (Julén, 1977). Any further mentioning of red clover in this text will be made in reference to the medium-late type.

Red clover is known to have a 13 to 16 h range of critical photoperiods for flowering depending on latitude of growth. Plants of northern origin have higher critical photoperiods than plants of southern origin (Bowley et al., 1984; Julén, 1977). Furthermore, red clover does not have a vernalization requirement (Bowley et al., 1984).

Alfalfa

Alfalfa is a herbaceous perennial that originated in areas near Iran (Barnes and Sheaffer, 1985). It is called the "Queen of forages" because of its high yielding capacity and high forage quality. Alfalfa is capable of surviving under extreme temperatures that range from -25 °C in Alaska to 50 °C in California (Barnes and Sheaffer, 1985). Although alfalfa is more drought tolerant than red clover because of its deeply set roots, it performs better on irrigated soils. During periods of severe drought alfalfa becomes dormant and it may be in a dormant state for up to two years if the drought persists (Barnes and Sheaffer, 1985).

Alfalfa is sensitive to acid soils and, therefore, pH values need to be in a range of 6.5 to 7.0 to maximize forage production (Rhykerd and Overdahl, 1972). Alfalfa also requires fertile soils. Especially K, P, S, and B are needed to produce abundant yields.

Alfalfa cultivars differ in crown type and stem number. Winter-hardy cultivars generally have larger crowns and more stems than cultivars that are less winter-
hardy. Cultivars that are less winter-hardy may produce up to 10 harvests per year in southwestern USA, whereas the winter-hardier types in the Midwest typically produce one to 3 harvests per year (Barnes and Sheaffer, 1985).

**Timothy**

Timothy is native to the Eurasian continent, but is grown throughout the temperate and subarctic climates (Childers and Hanson, 1985). Timothy is a perennial, noncompetitive bunchgrass that grows well under cool and humid conditions, but not under droughty conditions (Childers and Hanson, 1985). It produces many tillers with erect stems that are between 80 and 110 cm tall at maturity. New shoots develop from buds at the base of the culm below the haplocorm, a modified thickened stem base acting as a vegetative reproductive structure (Childers and Hanson, 1985).

Timothy has a considerable range between southern and northern cultivars in daylengths required for flowering (Childers and Hanson, 1985). A critical photoperiod between 13 and 16 h is often mentioned (Julén, 1977). Optimum growth temperatures lie between 15 and 22 °C (Childers and Hanson, 1985; Smith, 1970), although timothy is known to grow well even at temperatures below 10 °C.

Northern cultivars are more winter-hardy than southern cultivars (Klebesadel and Helm, 1986), but no cultivar has been reported to have a vernalization requirement (Fagerberg, 1988).

**Smooth bromegrass**

The genus *Bromus* consists of approximately 60 species that are native to Europe and Asia (Carlson and Newell, 1985). Smooth bromegrass is leafy, tall, and a sod-forming perennial that propagates either through seeds or underground rhizomes. In USA, smooth bromegrass is primarily adapted to areas in the Corn Belt and adjacent areas northward and westward (Carlson and Newell, 1985).
Smooth bromegrass is winter-hardy. Carlson and Wedin (1974) reported that smooth bromegrass was more winter hardy and higher yielding than orchardgrass (*Dactylis glomerata* L.), reed canarygrass (*Phalaris arundinacea* L.), and tall fescue (*Festuca arundinacea* Schreb.) in Iowa trials. Regrowth of smooth bromegrass is slow, however, because most tiller apices are removed by cutting.

Smooth bromegrass grows well on a variety of soil types including sandy loams, although it grows best on silt or clay loams that are fertile and well drained.

Smooth bromegrass cultivars are classified into three types: northern, intermediate, and southern, based on areas of adaptation (Carlson and Newell, 1985). Leaves on southern cultivars are wider, coarser, and originate at a lower level of the culm than northern types. Southern types also are more frost tolerant, produce denser sods, and start to grow earlier in the spring than northern types.

Environmental Effects on Plant Morphology

**Stage of development**

**Daylength** In the vast majority of flowering plants, environmental controls such as daylength and temperature modulate rate of development (J. Heslop-Harrison and Y. Heslop-Harrison, 1970). Higher than optimum temperatures shorten growth periods (Strand, 1987) resulting in plants having hastened maturity and herbage quality decline (Marten, 1970; Vough and Marten, 1971).

Both daylength and irradiance, the amount of photosynthetic energy supplied to a unit area per unit time to a plant, influence flowering and advancement of maturity (Thorvaldsson, 1987). Julén (1977) and Bowley et al. (1984) showed that a southern red clover cultivar under constant illumination has flower-formation ability already developed by the third to fifth leaf-stage, but flower
bearing stems are weak. Red clover of northern origin forms flowers at the 12th to 13th leaf-stage (Bowley et al., 1984). Therefore, the more that daylength exceeds the minimum requirement of a plant, the faster its development will be from the vegetative phase to flowering (Pulli, 1988). Pulli (1988), who used a range of red clover cultivars grown in Finland, found that no red clover cultivar flowered at a 12 h photoperiod, whereas at 20 h all red clover cultivars flowered regardless of origin. The northern-most cultivars flowered later than the southern cultivars, however. Ryle and Langer (1963) and Langer (1979) also found that various cultivars of timothy react differently to daylength. Some cultivars have a strict demand for a minimum daylength, whereas others flower earlier with longer days.

**Temperature** Increasing temperature increases the rate of maturation in forage crops (Deinum et al., 1981). Fagerberg (1988) reported that a temporary temperature reduction delayed flowering of red clover. Similar results have been shown for timothy for which anthesis was delayed at 16/11 °C (day/night temperatures) compared with plants grown at 26/21 °C (Labhart et al., 1983). Labhart et al. (1983) reported that this effect was reversed at the 50th day of growth because of increased leaf proportion and increased number of vegetative tillers at the higher temperature range. Langer (1979) also reported that high temperatures of timothy inhibits or delays flowering. In his study, however, inhibition occurred between 12 and 18 °C, which is a considerably lower temperature range than that reported by Labhart et al. (1983) to inhibit flowering.

Heide (1982) and Junntila (1985) reported that an interaction of daylength and temperature affected flowering in timothy. Higher temperatures and photoperiods increased maturation of timothy, but high temperatures (>12 °C) also increased the critical photoperiod for flowering.
Phenological schemes

Phenology involves the relation between time and duration of different developmental stages, such as leaf, bud, and flower development (Fagerberg, 1988; Ohlsson and Wedin, 1989). The time and duration of developmental stages are influenced by environmental factors such as daylength and temperature. Therefore, these predictable habits of development have been used by agronomists to describe growth of cash crops as well as forages. The tools through which description of growth patterns have been made include the use of phenological staging schemes (Elsner et al., 1979), such as those developed by Kalu and Fick (1981), Hedlund and Höglund (1983), Simon and Park (1981), and Ohlsson and Wedin (1989) for forage legumes and grasses.

Plant height

Stem length of red clover and timothy at maturity may range from 30 to 80 and 80 to 110 cm, respectively, depending on existing environmental conditions (Bowley et al. 1984; Ohlsson and Wedin, 1989; Taylor, 1985).

Increased daylengths increase stem height and increased temperature generally increases stem height when plants have comparable maturity stages (Ceulemans et al., 1986; Pulli, 1988). Plants exposed to extended photoperiods have rapid stem formation resulting in an underdeveloped leaf rosette and root system, the effect being more pronounced for early cultivars than for late cultivars (Pulli, 1988). Plant height, within the optimum range of temperature, increases because plant growth is promoted. Beyond optimum temperatures, however, stem height decreases because of shortened internodes (Bowley et al., 1984).

Experiments in which daylengths were extended with similar or dissimilar irradiance levels have resulted in increased stem heights in red clover and timothy. Pulli (1988) reported that stem height of red clover at first cut increased by 16 and 27%, respectively, as daylengths were extended 4 and 8 h beyond a 12-h
photoperiod. At second cut, stems were 49 and 65% taller, respectively. Pulli (1988) explained that stem development was prevented after first cut at the 12-h and 16-h photoperiods, thus explaining the larger differences in stem height between photoperiods in second cut. Heide et al. (1985) reported a three-fold increase in timothy stem height as photoperiods increased from 8 h to 24 h. The height differences reported by Heide et al. (1985) were a true photoperiodic effect since both treatments received the same total irradiance levels, whereas in the experiment by Pulli (1988) plants at the longer photoperiods also received more photosynthetic energy. Maddaloni (1972) found that tall fescue was shorter under normal daylight conditions compared with irradiance levels that were 50 to 70% of normal daylight. Thus, it appears that photoperiodic effects alone have a greater influence on stem height than when photoperiod and irradiance effects are combined.

Surprisingly, Pulli (1988) found no difference in height between red clover cultivars of variable latitude origin at 20-h daylengths. However, at 12-h and 16-h daylengths, southern cultivars were taller than northern cultivars.

**Tillering**

Tiller number shows a good correlation with forage yield, especially before tiller equilibrium is reached (Casier and Hovin, 1985; Zarrough et al., 1984). The increase in total number of tillers is exponential until competition or floral initiation occurs (Patel and Cooper, 1961). New vegetative tillers arise from buds in leaf axils for timothy (Patel and Cooper, 1961), and from the crown in red clover (Bowley et al., 1984). Tiller development in any axil usually does not begin until the leaf above is fully expanded (Patel and Cooper, 1961).

Both rate of leaf appearance and level at which tillering starts, and thus final tiller number, are limited largely by light energy in timothy (Patel and Cooper, 1961). The inhibition of tillering at lower nodes by low irradiance levels may be
related to insufficient levels of available carbohydrates at the axillary meristems (Patel and Cooper, 1961). Zarrough et al. (1984) reported, however, that tillering was not dependent on concentration of water soluble carbohydrates in either leaf, stem, or root fractions in tall fescue. Therefore, it seems that further studies are needed to resolve this issue.

As age of stands increase, tiller number is reduced by increased daylengths (Pulli, 1988). But Pulli (1988) found no differences in tiller number of red clover until after 60 days of growth for plants exposed to 12-, 16-, and 20-h daylengths. Tiller number at the sixth leaf stage of timothy is stimulated up to a 13-h photoperiod (Patel and Cooper, 1961), followed by a plateau or a slight decrease at daylength extensions up to 20 h (Patel and Cooper, 1961; Pulli, 1988).

Variable responses of tiller number to temperature have been reported. Tiller number remained constant for smooth bromegrass when temperatures decreased, whereas tiller number for timothy increased when temperature increased (Smith, 1970). Bowley et al. (1984) reported no change in tiller number for red clover as day/night temperatures increased from 15/10 °C to 32/27 °C. Furthermore, Heide et al. (1985) reported significant daylength by temperature interactions with respect to tillering of timothy as the photoperiod was extended from 8 to 24 h, with a 40% reduction at 12 °C compared with a 20% reduction at 15 °C.

These results imply that cultivars grown at northern latitudes where days are long and temperatures are low should produce fewer tillers, and thus less vegetative tissue to protect the root crown, than cultivars grown at lower latitudes. Pulli (1988) reported, however, that northern cultivars of red clover had more tillers than southern cultivars when they were grown at long daylengths. Natural selection seemingly has made northern cultivars well adapted to winter survival.
Leaf area

Leaf production at low temperatures and low irradiance is relatively poor, but increases considerably during long days and abundant radiation, as in northern growing regions (Pulli, 1988).

Increasing daylengths during early development result in increased leaf area and leaf size (Heide et al., 1985; Pulli, 1988). Leaf number, however, is not affected by daylength extensions (Heide et al., 1985). Pulli (1988) and Heide et al. (1985) reported that leaf areas doubled when photoperiods were extended 8 h and 16 h, respectively.

Supplemental irradiance increases the rate of leaf appearance and specific leaf weight (leaf weight divided by leaf area), however (Hay, 1989; Patel and Cooper, 1961; Pearce et al., 1968).

Reduction of original irradiance levels decreases leaf longevity. Few reports discuss the effect of daylength on leaf longevity, however. Extended photoperiods are known to accelerate maturity of plants. Therefore, it may be assumed that leaf duration is decreased with increasing daylengths.

In the optimal range of temperatures, leaf area increases as a result of stimulated growth (Heide et al., 1985; Pulli, 1988). At higher than optimum temperatures, leaf-area duration is shortened because photosynthetic tissue senesces (Austin, 1983; Biscoe and Gallagher, 1977).

Species and cultivars differ in rate of leaf appearance and size of leaves. These differences may result from differential responses to photoperiod, total irradiance, or temperature (Heide et al., 1985; Patel and Cooper, 1961; Pulli, 1988). Patel and Cooper (1961) reported that timothy had more rapid leaf production than perennial ryegrass (Lolium perenne L), especially in early summer. Pulli (1988) reported that northern cultivars of red clover had smaller leaf areas than southern cultivars when grown in identical environments. Contrary to the results of Pulli
Environmental Effects on Dry Matter Production and Distribution

Dry matter production

The signal for plants to grow is determined by daylength and temperature, both of which need to be longer and higher, respectively, for northern adapted species compared with southern species. Perennial species at northern latitudes initiate growth later and cease to grow earlier than long-day species grown at southern latitudes (Klebesadel, 1985; Rognli, 1988). Thus, the growing season is shorter in the north than in the south. Because of the short growing season at northern latitudes, forage species generally are harvested only once or twice per season (Rognli, 1988). At southern latitudes, more than two harvests generally are taken per growing season (Rognli, 1988).

The annual dry matter production for forage species decreases with increase in latitude (Hay, 1989; Rognli, 1988). The relative amount of dry matter produced from northern ecotypes at first harvest, however, also increases with increasing latitude of origin (Foss, 1968; Hay, 1989; Klebesadel and Helm, 1986). A physiological adaptation to long photoperiods and low temperatures of northern ecotypes have produced plants with large leaf areas and a prolonged period of vegetative growth because of delayed reproductive development at low temperatures. These characteristics have resulted in high spring growth rates for plants with northern adaptation (Deinum et al., 1981; Hay and Pedersen, 1986; Heide et al., 1985).

Plants grown at northern latitudes receive more photosynthetic energy per day than plants grown at lower latitudes (Haverkort, 1990). Increased irradiance
stimulates both photosynthesis and dry matter yield (Alberda, 1965; Thorvaldsson, 1987). Alberda (1965) also reported that an interaction between temperature and irradiance takes place so that an optimum temperature is dependent on irradiance, and the effect of irradiance varies with temperature. Furthermore, irradiance affects photosynthetic rate, but not respiration, whereas temperature influences both photosynthesis and respiration (Alberda, 1965).

Higher daily irradiance levels at northern latitudes are not solely responsible for increased dry matter production, however. Heide et al. (1985), and Hay and Heide (1983) reported that when photoperiods were extended, but irradiance levels kept constant, dry matter production was stimulated for timothy and smooth bromegrass. The stimulation, they claimed, was a result of increased interception of solar radiation (Hay and Heide, 1983; Hay and Pedersen, 1986; Heide et al., 1985). Their results are in conflict with findings of Faix (1974) who found that daylength had no definitive influence on alfalfa yields.

**Dry matter distribution among plant parts**

The general effects of environmental inputs on plant growth and development were described in the previous section. Dry matter partitioning among plant parts, however, is often differentially affected depending on level and time of environmental inputs. Furthermore, plants show no change in dry matter yield for the first 10 days, then there is a decrease until day 20 because of differentiation of plant tissue of the young seedling (Hunt, 1982).

Relative growth rates provide an integration of the combined performances of the various parts of the plant. They are especially useful when comparisons of species and treatment differences need to be done on a uniform basis. Relative growth rates on a whole-plant basis are not useful, however, "because they tell us nothing of the causal processes of the gross performance of the plant" with respect to partitioning of photosynthate (Hunt, 1982).
Root distribution and shoot:root ratios

Puill (1988) observed that root dry matter increases as daylengths are increased and irradiance levels are increased. He reported that red clover had 59 and 66% higher root weights at 16- and 20-h daylengths, respectively, compared with a 12-h daylength. As temperatures increase; however, root growth at long days decreases (Ewing, 1981).

Few reports have elaborated on dry matter partitioning of root, relative to that of shoot and leaf at high irradiances. Lower than normal irradiance, however, produce relatively more herbage than root material (Tysdal, 1933). At higher than normal radiation levels water soluble carbohydrates in roots change the least when compared with change of carbohydrate levels in stems and leaves (Labhart et al., 1983). Relatively lower accumulation of root growth compared with top growth is produced when plants are short of carbohydrates, such as for defoliated plants or plants with an abundance of inorganic N (Chapin, 1980).

Roots are less efficient in photosynthate assimilation than shoot and leaf material. Passioura (1983) reported that twice as much assimilate is required to produce one unit of root dry matter compared with that required to produce one unit of shoot dry matter. A partial explanation for this relationship is that up to 20% of the photosynthate is exuded from root tips (Clarkson, 1985). In contrast, Lambers et al. (1983) reported that the carbon cost of producing root material is similar to that of other plant parts. Further research is apparently needed to resolve these reported differences.

Increased maturity of plants, by means of either extended photoperiods or increased temperatures or both, increases the shoot:root ratio (Heide et al., 1985; Siddique et al., 1990). While drought stress is known to have a variable effect on maturity depending upon time of stress, the shoot:root ratio decreases with water stress (Hamblin and Tennant, 1987; Schultz, 1974).
Cultivars differ in root production under different environmental conditions. Cultivars of northern origin generally have larger root or rhizome systems than cultivars grown at southern latitudes (Rognli, 1988). This ensures sufficient storage of carbohydrates and early spring growth (Rognli, 1988). Pulli (1988) reported that differences in root weight of red clover cultivars of diverse origin were greatest at 16 h and smallest at 12-h daylengths. Plants grown at 20 h showed intermediate differences among cultivars. Surprisingly, and contrary to findings by Rognli (1988), Pulli (1988) also reported that the northern-most cultivar had the smallest root system at each daylength treatment.

Shoot and leaf dry matter distribution

Maturity of plants is a common denominator describing the decline in leaves relative to shoots even when interactions of environmental factors take place (Brignall et al., 1989; Marten, 1970; Deinum et al., 1981; Kilcher and Heinrichs, 1974). The decline in leaf growth relative to stem growth has been attributed to leaf loss and senescence (Kalu et al., 1990). Input time of environmental factors, however, may affect leaf and shoot production in a way that is unrelated to maturity of plants. Water stress, for example, retards plant development in early growth stages, but enhances plant development at later growth stages.

Deinum et al. (1981) reported that decreased leaf production relative to shoot production at higher latitudes was because of faster development compared with plants grown at lower latitudes. Hedlund and Höglund (1983) further stated that leaf:stem ratio changed more rapidly in grasses than in legumes because initially grasses only have leaves, whereas legumes have both leaves and stems. When temperatures were low at higher latitudes, plants matured more slowly and leaf:stem ratios increased (Labhart et al., 1983).

Shoot production during long days is favored over both root growth (Chapin, 1980) and leaf growth (Bowley et al., 1984; Deinum et al., 1981; Faix,
1974), although dry weight of all plant parts increase (Labhart et al., 1983). When plants are subjected to reduced radiation, leaf:stem ratios increase (Bowley et al., 1984), although leaf and stem production is relatively poor (Pulli, 1988). Conversely, increased radiation decreases leaf:stem ratio and increases water soluble carbohydrates in both stems and leaves (Labhart et al., 1983; Pearce et al., 1968).

Labhart et al. (1983) and Marten (1970) reported that leaf:stem ratios increase and decrease at low and high temperatures, respectively. Faix (1974) reported that leaf percentage increased at temperatures above 22 °C, however, for alfalfa and birdsfoot trefoil (*Lotus corniculatus* L.). Patel and Cooper (1961) reported that leaf production of perennial ryegrass, timothy, and meadow fescue (*Festuca pratensis* L.) in northern Europe show an increase up to 16 °C, followed by a plateau and a decrease beyond 24 °C. Although these results are conflicting, it seems that temperatures outside optimum ranges result in increased leaf:stem ratios.

Environmental Effects on Forage Quality

Forage quality is often used to predict or explain ruminant animal-performance. Forages with high fiber concentrations and low protein concentrations are considered to be of low quality. Both digestibility and crude protein (CP) concentrations decline with age (Thorvaldsson, 1987). Environmental factors such as daylength, solar radiation, temperature, soil water, and levels of available N influence digestibility, crude protein and fiber fractions of forages, however.
Digestibility

Digestibility of plants is determined primarily by cell-wall concentration and the digestibility of cell wall because cellular content is nearly 100% digestible (Thorvaldsson, 1987). Numerous studies report that daylength, temperature, and solar radiation affect both cell-wall concentrations and digestibility of forage crops (Deinum et al., 1981; Moir et al., 1977; Thompson et al., 1989; Thorvaldsson and Fagerberg, 1988).

Temperature

Temperature has a larger effect on digestibility than daylength and solar radiation in spring growth (Thorvaldsson and Fagerberg, 1988). Increased temperatures reduce the concentration of water soluble carbohydrates and have a detrimental effect on dry matter digestibility (Balasko and Smith, 1971; Deinum and Dirven, 1975; Marten, 1970; A. Smith, 1977; D. Smith, 1970, 1968). Deinum et al. (1968) showed that late spring growth of perennial ryegrass had 10% lower digestibility than early spring growth because of increased temperature and increased stem formation. Marten (1970) reported that high temperatures caused larger decreases in the digestibility of grasses than that of legumes at specific maturity stages.

Advancement of maturity, an effect caused partially by temperature, causes a decline in digestibility of forage crops. Grasses and legumes show similar total herbage digestibilities at similar maturity stages because legumes have relatively lower concentrations of hemicellulose and higher concentrations of cell solubles than grasses, whereas grasses have relatively lower concentrations of lignin (Marten, 1985). Digestibility of leaves in grasses, however, tend to decrease more than that of leaves in legumes (Hedlund and Höglund, 1983).

Mitchell (1987) stated that decline in quality of timothy and smooth bromegrass grown in Alaska was greater before head emergence than after head emergence. He attributed this difference to higher growth rates during earlier stages of development, thereby affecting nutrient dilution. Late-flowering cultivars
also showed a smaller decline in digestibility than early flowering cultivars (Deinum et al., 1981).

**Daylength** No clear direct effect of daylength on dry matter digestibility has been found (Allinson, 1971; Bowman and Law, 1964; Mannetje, 1975). Daylength has a large effect on stem elongation and flowering in herbage, however, and hence an indirect effect on herbage quality (Thorvaldsson, 1987).

Deinum et al. (1981) reported that digestibility of organic matter declined faster at higher latitudes because stem development proceeded faster and because less leaf dry matter was produced. Thus, the leaf:stem ratio decreases with increase in latitude and because leaves have lower digestibility than stems, total herbage digestibility also declines (Brignall et al., 1989; Kalu et al., 1990; Marten, 1970). In contrast, Deinum et al. (1981) reported that increased stem development at higher latitudes might not have much effect on digestibility because the more rapid development at northern latitudes does not have a negative effect on forage quality. Fiber deposition at northern latitudes apparently cannot keep pace with stem development, compared with plants grown at lower latitudes. Deinum et al. (1981) further reported that leaf digestibility decreased more slowly at higher latitudes than at lower latitudes; however, stem digestibility showed opposite effects. Stem digestibility declined more rapidly at northern latitudes because of faster reproductive development (Deinum et al., 1981).

**Irradiance** Thorvaldsson and Fagerberg (1988) reported that irradiance was negatively correlated to digestibility of organic matter in a second harvest of timothy. This may in fact be an indirect effect of temperature because high radiation levels often are associated with cloudless days and high temperatures (Peltonen, 1990). Deinum et al. (1981) reported that high radiation levels and high N supplies will promote herbage production without much effect on maturity and digestibility.
Crude protein and total N

Temperature Variable effects of temperature on CP concentrations have been reported. Marten (1970) found that plants often have lower CP concentration at high temperatures than at low temperatures. In contrast, Smith (1970) reported that CP concentrations were positively correlated with temperature while Deinum (1966) reported that various grass species had the lowest CP concentrations at optimum growth temperatures and higher CP concentrations either below or above these temperatures. These differences in results may be resolved if temperature effects on CP concentrations are considered in conjunction with temperature effects on dry matter production.

Increased temperature up to certain levels increase dry matter production. At low to moderate N-applications, CP concentrations will decrease (Thorvaldsson, 1987). At high N-applications, however, N uptake can increase faster than dry matter production, resulting in higher CP concentrations (Thorvaldsson, 1987).

Daylength Irradiance is important for the N status of a plant. Plants either use nitrate or ammonium as a source of soil N as it is ultimately incorporated into protein as amino acids. The form of N used depends on its availability in the soil and also varies with plant species. Light energy is needed to reduce nitrate to ammonium, which in turn is assimilated into amino acids and proteins. Thus, plants grown under low irradiance levels may have higher nitrate concentrations (Deinum, 1966) and consequently lower CP concentrations. The energy expenditure of reducing nitrate into amino acids is approximately seven to ten times higher than assimilating ammonium into amino acids (Chapin et al., 1987). Therefore, high irradiance levels permit nitrate assimilation at little carbon expense and should thus favor the use of nitrate. Conversely, low irradiance levels diminish nitrate reduction and therefore may reduce CP production if ammonium is limiting (Chapin et al., 1987).
Maximum rate of carbon assimilation by a single leaf at light saturation and under optimal growth conditions is highly correlated with leaf organic N concentrations (Chapin et al., 1987). Leaves with low N probably have low photosynthetic N-use efficiency because they invest a large proportion of total leaf N in nonphotosynthetic components, such as nucleic acids and proteins associated with cell regulation and respiration (Chapin et al., 1987).

**Stage of maturity** Crude protein concentration on a whole plant basis is negatively correlated to age of the plant. There are differences in the pattern of CP changes when looking at stem and leaf components individually, however. Kalu and Fick (1983) reported that CP concentrations in leaves of alfalfa increase three to nine percentage points in early vegetative stages, but then stabilize at levels between 25 and 30% CP.

Stem concentrations of CP decrease with age of the plant (Kalu and Fick, 1981). In alfalfa, the largest decrease occurs between early vegetative stages, followed by a plateau and a decrease that is less than two percentage points. These changes may seem relatively low. Considering a decrease in leaf:stem ratio with age, leaf drop and senescence, and that leaf CP concentrations already are higher than stem CP concentrations, however, the total herbage decline in CP concentration may be substantial. Kilcher and Heinrichs (1974) reported that total CP concentrations of alfalfa grown in Saskatchewan, Canada, decreased from 22.8 to 13.2% during an 8-week period.
MATERIALS AND METHODS

Growth Chamber Experiments

Experiments and cultivars

Two cultivars of red clover and timothy were used in two growth-chamber experiments. Experiment 1 was conducted in fall of 1989 and Experiment 2 in spring of 1990. Both experiments were similar and thus, the following description of treatments and management apply to both. There was one cultivar of American origin and one cultivar of Swedish origin for both red clover and timothy. Red clover cultivars were 'Arlington' (American) and 'Hermes II' (Swedish). Timothy cultivars were 'Timfor' (American) and 'Kämpe II' (Swedish). Experimental treatments applied to the four cultivars were a factorial combination of 10-, 15-, or 20-h daylengths with 10 or 20 °C constant temperatures.

'Arlington' is a medium-late type of red clover developed by the University of Wisconsin, Madison and United States Department of Agriculture (USDA) and released in 1973. It is resistant to powdery mildew and northern anthracnose and has moderate resistance to bean yellow mosaic virus. 'Hermes II' is a Swedish medium-late type developed by Svalöf AB, Svalöv, Sweden and released in 1968.

'Timfor' is a medium-late type of timothy released by Northrup King and Co. in 1971, and 'Kämpe II' is a medium-late type released by Weibulls plant breeding station in Landskrona, Sweden. Kämpe II is leafy and rust resistant.

Seedling establishment

Seeds were germinated on sand flats. After four days of germination, seedlings were placed in a cold room for vernalization for 14 days at 5 °C. Although no vernalization requirement has been reported for either species, it is known to stimulate flowering (Fagerberg, 1988). Ten vernalized seedlings from
each cultivar were transplanted from sand flats to 15-cm diameter by 15-cm high pots containing sand. A total of 150 pots per cultivar were placed on greenhouse benches on 5 December 1988 and 5 June 1989, respectively. Plants were grown for 10 weeks at a 15-h daylength and 20 °C. Plants were watered once to twice daily and fertilized with a liquid nutrient solution (Peter's Professional 20:10:20 mixed at 1 kg fertilizer 400 L⁻¹ water) weekly.

**Growth chambers**

After 10 weeks, plants were cut to 5 cm, herbage was weighed and discarded, and 25 pots per cultivar were randomly assigned to each of six Receptive growth chambers in Experiment 1 and each of six Conviron growth chambers in Experiment 2. In each experiment, each growth chamber was subjected to one of the six daylength by temperature treatment combinations. Photosynthetic photon flux density (PPFD) was maintained at 470 μmol m⁻²s⁻¹ and 650 m⁻²s⁻¹ in Experiments 1 and 2, respectively. Plants were grown in the growth chambers for 10 days before being subjected to seven weekly harvests (harvest 1 through 7). Plants from four pots per cultivar were removed from each chamber at harvests 1, 3, 5, and 7. Plants from three pots per cultivar were removed from each chamber at harvests 2, 4, and 6. Remaining pots in chambers were re-randomized after each harvest. Spacing between pots was equal for all harvests to avoid differential competition for PPFD. Dry weights decreased between harvests 1 and 2 in most treatments, an indication that plants were not adapted to growth chamber conditions. Therefore, it was decided to exclude data from harvest 1 in statistical analyses.
Measurements and calculations

At each harvest, sand was washed from roots. Plant material from each pot was then placed in a plastic bag and stored in a refrigerator at 4 °C until the following measurements could be done:

Stage of maturity was determined from one phenological scheme developed for red clover (Hedlund and Höglund, 1983) and one scheme developed for timothy (Hedlund and Höglund, 1983). A detailed explanation of the schemes is found in the article of Ohlsson and Wedin (1989). Ten tillers per pot were selected at random and a maturity stage was recorded for each tiller. A mean stage value was then calculated based on 10 tillers (MSC; Kalu and Fick, 1983) according to the following formula:

\[
MSC = \frac{\Sigma (Sc+Sn)}{\Sigma Sn}
\]

where MSC=Mean stage by count, Sc=Stage category, and Sn=Stem number

Plant height, measured from the base of the stem to the tip of the uppermost leaf on one tiller per pot (cm).

Number of tillers developed from each plant.

Root dry weight. All tissue below the stem base was considered root material (g per pot).

Shoot dry weight. Shoots included stem, sheath, and inflorescence of timothy, and stem, petiole, and inflorescence of red clover (g per pot).
Leaf dry weight. Leaf material consisted of leaf blade of timothy, and leaflets of red clover (g per pot).

Leaf area measured on a leaf area meter (LICOR 3100, Lincoln NE) for harvests 2, 4, and 6 (cm² per pot).

Leaf:stem ratio. The ratio was calculated as leaf dry weight divided by shoot dry weight (g g⁻¹).

Shoot:root ratio. The ratio was calculated as shoot dry weight divided by root dry weight (g g⁻¹).

Specific leaf weight. Calculated as leaf weight divided by leaf area on a per pot basis (g m⁻²).

After these measurements were completed, leaves, shoots, and roots from each pot were separated and dried in a forced-air oven for 48 h at 55 °C. After leaf, shoot, and root dry matter were determined, leaf and shoot material were ground in a Cyclone mill to pass a 1-mm screen.

Red clover and timothy samples were scanned separately in each experiment on a NIRSystems 6250 near infrared spectrophotometer (NIRS) (Silver Springs, MD). In Experiment 1, 290 and 288 red clover and timothy samples were scanned, respectively. In Experiment 2, 300 samples of each species were scanned. The SELECT option on Infrasoft ver. 2.0 software was used to detect sample outliers. Samples with a larger h-value than 3.0 were re-scanned and eliminated from the data set if the h-value continued to be larger than 3.0. The SUBSET option on Infrasoft ver. 2.0 software was used to select samples for calibration of scanned values. An h-value equal to 0.7 or less was used for both
red clover and timothy. In Experiment 1, 88 and 74 samples were selected for red
clover and timothy, respectively. In Experiment 2, 91 and 73 samples were
selected for red clover and timothy respectively.

*In vitro* dry matter digestibility (IVDMD; Van Soest and Robertson, 1980) and
Kjeldahl N (N; Bremner and Breitenbeck, 1983) were determined for each sample
included in the calibration of NIRS. Separate equations for IVDMD and N for each
experiment and species were developed by using a modified partial-least-squares
procedure. This procedure involved three cross validations within a calibration set.
The spectra that caused the lowest standard error of calibration (SEC) and
standard error of validation of calibrated samples (SEV(C)) were used to develop
IVDMD and N equations. Because equations within species were not different
between experiments they were combined (Table 1).

<table>
<thead>
<tr>
<th>Quality</th>
<th>Sample number</th>
<th>SEC</th>
<th>R²</th>
<th>SEV(C)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVDMD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red clover</td>
<td>166</td>
<td>16.23</td>
<td>0.89</td>
<td>19.11</td>
<td>0.84</td>
</tr>
<tr>
<td>N</td>
<td>171</td>
<td>1.36</td>
<td>0.98</td>
<td>1.50</td>
<td>0.98</td>
</tr>
<tr>
<td>IVDMD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timmy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>145</td>
<td>23.08</td>
<td>0.83</td>
<td>25.81</td>
<td>0.79</td>
</tr>
<tr>
<td>N</td>
<td>139</td>
<td>1.46</td>
<td>0.98</td>
<td>1.88</td>
<td>0.97</td>
</tr>
</tbody>
</table>

*Standard error of calibration (g kg⁻¹).*

*Standard error of validation of calibrated samples (g kg⁻¹).*
Statistical analyses were performed separately on each species assuming a split plot design with the two experiments combined. Daylengths and temperatures were in whole plots, and cultivars and harvests were in split plots. There were four replications in harvests 3, 5, and 7, and three replications in harvests 2, 4, and 6. Pots were completely randomized within each chamber and they were re-randomized after each harvest.

The structure of the analysis of variance for each species is summarized in Table A1. An analysis of covariance with stage of maturity as a covariable was performed to test if treatment differences were caused by maturity.
Field Experiments

General description of experiment

One cultivar of American origin and one cultivar of Swedish origin in each of alfalfa, red clover, timothy, and smooth bromegrass were grown to compare maturity changes, digestibility, and fiber deposition at Ames, IA, Arlington, WI, Rosemount, MN, and Grand Rapids, MN in 1984 and 1985. Daylengths and latitudes for each location are described in Table 2.

In 1984, alfalfa and red clover were not sampled at Grand Rapids due to winter kill. The final harvest of timothy and smooth bromegrass was mistakenly omitted at Grand Rapids. Timothy and smooth bromegrass were not sampled at Rosemount because of difficulty in establishment. The stands of bromegrass at Arlington were weakened because of deer grazing in the fall following establishment. There were no missing samples at either location in 1985.

Site characteristics and fertilization

Cultivars of each species were solo-seeded in the first and second week of May in 1983 and 1984 at each location. The soil types at each location were as follows:

Ames, IA: Webster silty clay loam [fine-loamy, mixed, mesic Typic Haplaquolls].

Arlington, WI: Ringwood silty loam [fine-loamy, mixed, mesic Aquic Agriudolls].

Rosemount, MN: Waukegan silt loam [fine-silty over sandy, mixed, mesic, Typic Hapludolls].

Grand Rapids, MN: Cowhorn sandy loam [course-loamy, mixed, nonacid sand, frigid, Aeric Haploquepts].
Table 2. Latitude at sampling sites and daylength for 15-day intervals during early spring growth

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>1 May</th>
<th>16 May</th>
<th>1 June</th>
<th>16 June</th>
<th>1 July</th>
<th>16 July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>42</td>
<td>14:02</td>
<td>14:35</td>
<td>15:02</td>
<td>15:14</td>
<td>15:11</td>
<td>14:55</td>
</tr>
</tbody>
</table>
The pH levels were between 6.0 and 6.5 at each location and year. Nonlimiting levels of 50 kg ha\(^{-1}\) of P and 300 kg ha\(^{-1}\) of K according to soil tests were maintained at each site. Grasses were fertilized with 90 kg ha\(^{-1}\) of N as NH\(_4\)NO\(_3\) two weeks before sampling one year following establishment. Legumes received no N-fertilizer.

Experimental design and forage sampling

Each species was planted in 10-cm rows in 2.4 by 7.6-m plots by using a one-row hand seeder in each year. Cultivar description and seeding rates are presented in Table 3.

Samples for forage quality and stage of development for each cultivar were harvested weekly during an eight week period. Sampling began on 10 May and 1 May at Ames and Arlington in 1984 and 1985, respectively. Sampling was one week later in Rosemount and two weeks later in Grand Rapids each year. A split-split-split-split-plot in a randomized complete block design was used (four replications). Whole plots consisted of the four locations. Each sub-plot, which measured 1.2 by 7.6-m, consisted of American and Swedish cultivars of alfalfa, red clover, timothy, and smooth bromegrass. Cultivars within each species were planted next to each other. Each sub-sub-plot consisted of eight completely randomized areas measuring 0.18 m\(^2\). One sub-sub-plot in each block was harvested in eight weekly intervals. The sub-sub-plot was divided into two equal areas each measuring 0.3 by 0.3-m, in which one quality and one stage sample were harvested. Samples taken for quality were hand-clipped 5 cm above ground level and then dried in a forced-draft oven at 60 °C for 48 h. After drying, samples were ground to pass a 2-mm screen of a Wiley mill and then re-ground to pass a 1-mm screen of a Cyclone mill. Staging samples were hand-clipped at ground level and put into plastic bags. All staging samples were stored in a refrigerator at 4 °C until phenological stages could be determined in the laboratory.
Table 3. Species, cultivars, and their seeding rates in 1984 and 1985

<table>
<thead>
<tr>
<th>Species</th>
<th>American cultivar</th>
<th>Swedish cultivar</th>
<th>Seeding rate kg ha&lt;sup&gt;-1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>Apollo II</td>
<td>Vertus</td>
<td>15</td>
</tr>
<tr>
<td>Red clover</td>
<td>Arlington</td>
<td>Hermes II</td>
<td>12</td>
</tr>
<tr>
<td>Timothy</td>
<td>Timfor</td>
<td>Kämpe II</td>
<td>14</td>
</tr>
<tr>
<td>Bromegrass</td>
<td>Barton</td>
<td>Svaja</td>
<td>20</td>
</tr>
</tbody>
</table>
Staging procedures and calculations

Stage of development for alfalfa and red clover was determined by using the scheme of Kalu and Fick (1981). Because this scheme was originally developed for alfalfa, certain stage descriptions were modified for red clover use (Ohlsson and Wedin, 1989). Stage of development for each grass was determined by using the scheme of Simon and Park (1981). A stage value for each legume plant within a samples was determined, whereas only the 20 most mature grass stems were used to determine a stage value.

Mean stage values for each sample were calculated as follows:

\[
\text{MSW} = \frac{\sum (Sc \times Sw)}{\sum Sw}
\]

where \( \text{MSW} = \) Mean stage by weight, \( Sc = \) Stage category, \( Sw = \) Sample weight

Chemical analyses

After completion of the experiment each year, ground forage samples were sent to Iowa State University for quality determinations. The procedure described by Marten and Barnes (1979) was used to evaluate *in vitro* dry matter digestibility (IVDMD). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were conducted according to Goering and Van Soest (1970). Nitrogen concentrations were determined by using the procedure of Bremner and Breitenbeck (1983).

All samples were run in duplicates and re-run if differences between duplicates were greater than 1.5 g kg\(^{-1}\) for N, 25 g kg\(^{-1}\) for IVDMD, 15 g kg\(^{-1}\) for NDF and ADF, and 5 g kg\(^{-1}\) for ADL.

Near infrared reflectance spectroscopy

In 1984 and 1985, 20% of the quality samples were randomly selected for chemical analyses of the aforementioned quality factors. These samples were
used to calibrate a Near Infrared Reflectance Spectrometer (NIRS) at the University of Minnesota, St. Paul, Minnesota on a Pacific Scientific Model 6250 monochromator operated in conjunction with a Digital Equipment Company computer model 1123 (Marten et al., 1985). One equation was developed for legumes (alfalfa and red clover) and one equation was developed for grasses (timothy and smooth bromegrass) in each year. Statistics concerning calibration, validation, and performance of equations are listed in Table 4.

Weather data

Weather data from Ames, Arlington, Rosemount, and Grand Rapids are provided in Tables 5, 6, 7, and 8. In general, temperatures were lower and precipitation higher during the sample periods in 1984 compared with 1985.

Statistical analyses

Data were analyzed by species and year because red clover was missing at Grand Rapids, MN, and timothy was missing at Rosemount, MN in 1984. Thus, no statistical significance will be given to yearly differences or species interactions in the text. Analysis of covariance was conducted by using MSW as a covariable to test if location, cultivar, and harvest effects in addition to the various interactions were caused by maturity differences. The analysis of variance table that applies to each species is found in Table A2.
Table 4. Statistics for equation development, equation validation, and equation performance for quality samples of alfalfa and red clover (legumes), and timothy and smooth bromegrass (grasses) that were scanned on a Pacific Scientific Model 6250 near infrared reflectance spectrometer.

<table>
<thead>
<tr>
<th>Quality</th>
<th>Development</th>
<th>Validation</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>SEC</td>
<td>R²</td>
</tr>
<tr>
<td><strong>Legumes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>1.88</td>
<td>0.95</td>
</tr>
<tr>
<td>IVDMD</td>
<td>94</td>
<td>18.60</td>
<td>0.93</td>
</tr>
<tr>
<td>NDF</td>
<td>90</td>
<td>21.84</td>
<td>0.95</td>
</tr>
<tr>
<td>ADF</td>
<td>93</td>
<td>21.84</td>
<td>0.95</td>
</tr>
<tr>
<td>ADL</td>
<td>93</td>
<td>5.21</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Grasses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>132</td>
<td>1.37</td>
<td>0.99</td>
</tr>
<tr>
<td>IVDMD</td>
<td>157</td>
<td>19.57</td>
<td>0.95</td>
</tr>
<tr>
<td>NDF</td>
<td>94</td>
<td>13.54</td>
<td>0.97</td>
</tr>
<tr>
<td>ADF</td>
<td>128</td>
<td>13.28</td>
<td>0.97</td>
</tr>
<tr>
<td>ADL</td>
<td>126</td>
<td>6.24</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Equations were developed for total Kjeldahl nitrogen (N), in vitro dry matter digestibility (IVDMD), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL).
Table 5. Temperature and precipitation characteristics at Ames, Iowa in 1984 and 1985

<table>
<thead>
<tr>
<th>Harvest</th>
<th>Mean daily temperature&lt;sup&gt;a&lt;/sup&gt;</th>
<th>GDD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Precipitation&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>°C week</td>
<td>mm week</td>
</tr>
<tr>
<td>1</td>
<td>10.6 14.7</td>
<td>181 298</td>
<td>4 8</td>
</tr>
<tr>
<td>2</td>
<td>16.9 16.9</td>
<td>264 382</td>
<td>6 18</td>
</tr>
<tr>
<td>3</td>
<td>19.7 18.9</td>
<td>368 479</td>
<td>35 28</td>
</tr>
<tr>
<td>4</td>
<td>13.1 16.0</td>
<td>424 556</td>
<td>122 32</td>
</tr>
<tr>
<td>5</td>
<td>21.9 19.3</td>
<td>543 656</td>
<td>133 34</td>
</tr>
<tr>
<td>6</td>
<td>21.3 18.6</td>
<td>657 751</td>
<td>213 57</td>
</tr>
<tr>
<td>7</td>
<td>22.9 21.3</td>
<td>782 865</td>
<td>278 71</td>
</tr>
<tr>
<td>8</td>
<td>23.1 18.0</td>
<td>910 956</td>
<td>289 85</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean daily temperatures one week preceding each harvest.

<sup>b</sup>Accumulated growing degree days from 1 January up to one week preceding each harvest. Negative accumulations were equal to zero. The following formula was used to calculate growing degree days: \( GDD = \frac{(Min + Max^a C)}{2} - 5^\circ C \).

<sup>c</sup>Accumulated precipitation up to one week preceding each harvest.
Table 6. Temperature and precipitation characteristics at Arlington, Wisconsin in 1984 and 1985

<table>
<thead>
<tr>
<th>Harvest</th>
<th>Mean daily temperature&lt;sup&gt;a&lt;/sup&gt;</th>
<th>GDD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Precipitation&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1984 °C week</td>
<td>1985 °C week</td>
<td>1984 mm week</td>
</tr>
<tr>
<td>1</td>
<td>12.7 °C</td>
<td>146 °C</td>
<td>251 mm</td>
</tr>
<tr>
<td>2</td>
<td>16.3 °C</td>
<td>199 °C</td>
<td>330 mm</td>
</tr>
<tr>
<td>3</td>
<td>18.3 °C</td>
<td>280 °C</td>
<td>423 mm</td>
</tr>
<tr>
<td>4</td>
<td>15.6 °C</td>
<td>334 °C</td>
<td>497 mm</td>
</tr>
<tr>
<td>5</td>
<td>18.8 °C</td>
<td>426 °C</td>
<td>607 mm</td>
</tr>
<tr>
<td>6</td>
<td>15.7 °C</td>
<td>541 °C</td>
<td>671 mm</td>
</tr>
<tr>
<td>7</td>
<td>18.3 °C</td>
<td>654 °C</td>
<td>765 mm</td>
</tr>
<tr>
<td>8</td>
<td>17.2 °C</td>
<td>766 °C</td>
<td>850 mm</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean daily temperatures one week preceding each harvest. No mean daily temperatures were recorded in 1984.

<sup>b</sup>Accumulated growing degree days from 1 January up to one week preceding each harvest. Negative accumulations were considered equal to zero. The following formula was used to calculate growing degree days: \[ GDD = \frac{(Min + Max^°C)}{2} - 5^°C. \]

<sup>c</sup>Accumulated precipitation up to one week preceding each harvest.

<sup>d</sup>Only maximum and minimum temperatures were recorded in 1984. Therefore, no good estimate of average daily temperatures exists.
Table 7. Temperature and precipitation characteristics at Rosemount, Minnesota in 1984 and 1985

<table>
<thead>
<tr>
<th>Harvest</th>
<th>Mean daily temperature(^a)</th>
<th>GDD(^b)</th>
<th>Precipitation(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.2</td>
<td>16.7</td>
<td>221</td>
</tr>
<tr>
<td>2</td>
<td>18.4</td>
<td>18.3</td>
<td>288</td>
</tr>
<tr>
<td>3</td>
<td>14.7</td>
<td>14.3</td>
<td>366</td>
</tr>
<tr>
<td>4</td>
<td>22.3</td>
<td>18.1</td>
<td>470</td>
</tr>
<tr>
<td>5</td>
<td>19.1</td>
<td>13.5</td>
<td>568</td>
</tr>
<tr>
<td>6</td>
<td>20.3</td>
<td>18.9</td>
<td>660</td>
</tr>
<tr>
<td>7</td>
<td>21.2</td>
<td>16.9</td>
<td>773</td>
</tr>
<tr>
<td>8</td>
<td>21.4</td>
<td>21.6</td>
<td>888</td>
</tr>
</tbody>
</table>

\(^a\)Mean daily temperatures one week preceding each harvest.
\(^b\)Accumulated growing degree days from 1 January up to one week preceding each harvest. Negative accumulations were equal to zero. The following formula was used to calculate growing degree days:

\[
GDD = \frac{(Min + Max \times 5^\circ C)}{2} - 5^\circ C.
\]

\(^c\)Accumulated precipitation up to one week preceding each harvest.
Table 8. Temperature and precipitation characteristics at Grand Rapids, Minnesota in 1984 and 1985

<table>
<thead>
<tr>
<th>Harvest</th>
<th>Mean daily temperature(^a)</th>
<th>GDD(^b)</th>
<th>Precipitation(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.7</td>
<td>13.5</td>
<td>226</td>
</tr>
<tr>
<td>2</td>
<td>11.7</td>
<td>14.2</td>
<td>266</td>
</tr>
<tr>
<td>3</td>
<td>19.4</td>
<td>12.7</td>
<td>367</td>
</tr>
<tr>
<td>4</td>
<td>15.3</td>
<td>11.1</td>
<td>439</td>
</tr>
<tr>
<td>5</td>
<td>16.8</td>
<td>15.3</td>
<td>521</td>
</tr>
<tr>
<td>6</td>
<td>18.5</td>
<td>15.4</td>
<td>629</td>
</tr>
<tr>
<td>7</td>
<td>18.9</td>
<td>15.5</td>
<td>726</td>
</tr>
<tr>
<td>8</td>
<td>(d)</td>
<td>18.6</td>
<td>.</td>
</tr>
</tbody>
</table>

\(^a\)Mean daily temperatures one week preceding each harvest.

\(^b\)Accumulated growing degree days from 1 January up to one week preceding each harvest. Negative accumulations were equal to zero. The following formula was used to calculate growing degree days: 
\[
GDD = \frac{(\text{Max}^\circ C - \text{Min}^\circ C)}{2} - 5^\circ C.
\]

\(^c\)Accumulated precipitation up to one week preceding each harvest.

\(^d\)Harvest 8 was mistakenly omitted in 1984.
RESULTS AND DISCUSSION

Red Clover - Growth Chamber

Morphological characteristics

The effects of daylength, temperature, and cultivar on stage of maturity, plant height, tiller number, leaf area, and specific leaf weight will be discussed in this section.

Daylength and daylength interactions Tiller number was unaffected by daylength treatments, whereas stage of maturity, plant height, leaf area, and specific leaf weight increased 31, 32, 66, and 21%, respectively when daylengths increased from 10 h to 20 h (Table 9). Stage of maturity increased 2.4 times more between 15 h and 20 h than between 10 h and 15 h. This effect is probably attributed to the critical photoperiod of 13 to 16 h for red clover (Julén, 1977).

Stage of maturity increased curvilinearly over harvests and the increase was different for the three daylengths (Fig. 1). Plants at the 20-h daylength reached a plateau at approximately stage 36 and then decreased, whereas plants in the other daylength treatments initially lagged in development, but increased thereafter. Growth rates are known to decrease when plants reach reproductive development (Mitchell, 1987). Although observed mean stage values indicated that plants in the 20-h treatment only were in the sixth-node stage, many plants had reached full bloom. Furthermore, development of new tillers contributed to the low mean stage values. Flowering was less prominent in the 15-h treatment and no flowering occurred in the 10-h treatment. Therefore, the low incidence of flowering at the shorter daylengths probably explain the continuous increase in stage of maturity.

Plant height increased linearly over time and increased with increasing daylength (Fig. 2). Unlike stage of maturity, plant height was nearly equally
Table 9. Daylength effects on morphological characteristics averaged over two red clover cultivars

<table>
<thead>
<tr>
<th>Daylength</th>
<th>MSC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Height</th>
<th>Tiller</th>
<th>Leaf area</th>
<th>SLW&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>cm</td>
<td>no. pot&lt;sup&gt;1&lt;/sup&gt;</td>
<td>cm&lt;sup&gt;2&lt;/sup&gt; pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>25.4</td>
<td>16.5</td>
<td>48.5</td>
<td>680</td>
<td>44.7</td>
</tr>
<tr>
<td>15</td>
<td>27.7</td>
<td>19.2</td>
<td>50.2</td>
<td>951</td>
<td>48.9</td>
</tr>
<tr>
<td>20</td>
<td>33.2</td>
<td>21.7</td>
<td>49.7</td>
<td>1130</td>
<td>54.3</td>
</tr>
<tr>
<td>Mean</td>
<td>28.8</td>
<td>19.1</td>
<td>49.5</td>
<td>920</td>
<td>49.3</td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.1</td>
<td>2.9</td>
<td>6.3</td>
<td>124</td>
<td>3.1</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0023</td>
<td>0.2885</td>
<td>0.9568</td>
<td>0.1204</td>
<td>0.1747</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage value based on mean stage by count.

<sup>b</sup>Specific leaf weight.

<sup>c</sup>Standard error of a daylength mean (5 df).

<sup>d</sup>Probability of a larger F-value for daylength effects.
Figure 1. Regressions of mean stage by count values on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE = Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0001
Figure 2. Regressions of plant height on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0077.
stimulated for the three daylengths, indicating that increases in plant height are caused by supplemental radiation, but not limited by a critical photoperiod.

Leaf area increased linearly over time and increased with increasing daylength (Fig. 3). Most of the increase in leaf area occurred between 10-h and 15-h daylengths. The rates of change were approximately the same for the 15-h and 20-h daylengths, and were greater than the rate of change at the 10-h daylength. One reason for the small stimulation beyond 15-h daylength may be because of leaf drop and senescence at 20-h daylength. Senescence of leaves was especially obvious for plants grown at 20 h and 20 °C.

**Temperature and temperature interactions**

Stage of maturity, plant height, and leaf area increased 21, 19, and 18%, respectively with a 10 °C increase in temperature, whereas tiller number and specific leaf weight decreased 21 and 4%, respectively (Table 10). Therefore, only tiller number was more affected by temperature than by daylength with respect to morphological characteristics in this study (Tables 9 and 10).

Stage of maturity increased curvilinearly over time at 20 °C, whereas it increased linearly at 10 °C (Fig. 4). The daylength by temperature interaction was significant at $P<0.02$ (data not shown). Maturity changed in a similar manner at 20 °C as it did at the 20-h daylength, although the long daylength caused both a greater rate of change and higher absolute values (Figs. 1 and 4). Furthermore, changes in maturity at 10 °C were similar to those at 15-h daylength (Figs. 1 and 4), although plants grown at 15 h had slightly higher mean stage values. Thus, it is likely that at daylengths beyond 15 h, daylength takes precedent over temperature because MSC values at 20 °C plateau later and at lower MSC values than plants grown at 20-h daylength. At daylengths below 15 h, temperature takes precedent over daylength because MSC values are lower at 10 h and lag in development occurs for a longer time than for plants grown at 10 °C (Figs. 1 and 4).
Figure 3. Regressions of leaf area on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0263.
Table 10. Temperature effects on morphological characteristics averaged over two red clover cultivars

<table>
<thead>
<tr>
<th>Temperature</th>
<th>MSC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Height</th>
<th>Tillers</th>
<th>Leaf area</th>
<th>SLW&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>cm</td>
<td>no. pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>cm&lt;sup&gt;2&lt;/sup&gt; pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g m&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>26.0</td>
<td>17.5</td>
<td>55.6</td>
<td>846</td>
<td>50.1</td>
</tr>
<tr>
<td>20</td>
<td>31.5</td>
<td>20.8</td>
<td>43.4</td>
<td>999</td>
<td>48.3</td>
</tr>
<tr>
<td>Mean</td>
<td>28.8</td>
<td>19.2</td>
<td>49.5</td>
<td>923</td>
<td>49.2</td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.9</td>
<td>2.4</td>
<td>5.2</td>
<td>101</td>
<td>2.5</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0017</td>
<td>0.2164</td>
<td>0.0604</td>
<td>0.4075</td>
<td>0.1365</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage value based on mean stage by count.
<sup>b</sup>Specific leaf weight.
<sup>c</sup>Standard error of a temperature mean (5 df).
<sup>d</sup>Probability of a larger F-value for temperature effects.
Figure 4. Regressions of mean stage by count values on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0007.
Plant height increased curvilinearly over time in both temperature treatments although the change occurred in different ways (Fig. 5). These results indicate that the temperatures used in this study limited plant height for various reasons. Plants grown at 10 °C likely lagged at the initial harvests because of lower than optimum temperature for growth. The plateau at the later harvests at 20 °C is likely caused by a combination of water stress and shortened internodes as a result of the high temperature (Bowley et al., 1984).

Leaf areas tended to increase at a higher rate over harvests at 10 °C than at 20 °C (Fig. 6). Plants grown at 10 °C had higher leaf areas than those grown at 20 °C at the time when stage of maturity plateaued at 20 °C (Figs. 4 and 6). Furthermore, leaf drop and senescence occurred earlier and more rapidly for plants grown at 20 °C than those grown at 10 °C. The daylength by temperature by harvest interaction was significant for leaf area (P<0.0001; data not shown), indicating that both long days and high temperature affect leaf area negatively.

Tiller number increased more rapidly over time at 10 °C than at 20 °C (Fig. 7). Previous experiments provide conflicting results with regard to the temperature effect on tillering. Bowley et al. (1984) reported that a 16 °C-temperature increase had no effect on tiller number of red clover. Results from their study used a temperature range that was 5 to 10 °C higher than in this study. Smith (1970) reported that tiller number of timothy decreased as temperature increased.

Cultivar and cultivar interactions Arlington was more mature, taller, and had greater leaf area, but had fewer tillers and lower specific leaf weight than Hermes II (Table 11). Differences in stage of maturity between cultivars were related to both daylength and temperature (Table 12). Hermes II only reached reproductive development at 20-h daylength at 10 °C. Furthermore, bud development was reached 14 days earlier than for Arlington, indicating that Hermes II is better adapted for reproductive development at lower temperatures than Arlington. At 20 °C, reproductive development was reached at all daylengths,
Figure 5. Regressions of plant height on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0023.
Figure 6. Regressions of leaf area on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. Leaf areas only were determined every two harvests in each experiment. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0569.
Figure 7. Regressions of tiller number on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at $P=0.0009$
Table 11. Cultivar effects on morphological characteristics for Arlington and Hermes II red clover

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSC(^a)</th>
<th>Height</th>
<th>Tillers</th>
<th>Leaf area</th>
<th>SLW(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>no. pot(^{-1})</td>
<td>cm(^2) pot(^{-1})</td>
<td>g m(^{-2})</td>
<td></td>
</tr>
<tr>
<td>Arlington</td>
<td>31.1</td>
<td>20.3</td>
<td>49.2</td>
<td>931</td>
<td>48.1</td>
</tr>
<tr>
<td>Hermes II</td>
<td>26.4</td>
<td>18.0</td>
<td>49.7</td>
<td>855</td>
<td>50.4</td>
</tr>
<tr>
<td>Mean</td>
<td>28.8</td>
<td>19.2</td>
<td>49.5</td>
<td>893</td>
<td>49.3</td>
</tr>
<tr>
<td>SE(^c)</td>
<td>0.5</td>
<td>0.6</td>
<td>1.1</td>
<td>29</td>
<td>1.3</td>
</tr>
<tr>
<td>P&gt;F(^d)</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.5948</td>
<td>0.1601</td>
<td>0.2039</td>
</tr>
</tbody>
</table>

\(^a\)Mean stage value based on mean stage by count.

\(^b\)Specific leaf weight.

\(^c\)Standard error of a cultivar mean (429 df).

\(^d\)Probability of a larger F-value for cultivar effects.
Table 12. Highest reproductive stage (up to flowering) for 'Arlington' and 'Hermes II' red clover after specified number of days in each daylength and temperature treatment

<table>
<thead>
<tr>
<th>Daylength</th>
<th>Temperature</th>
<th>Arlington</th>
<th></th>
<th>Hermes II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>Stage</td>
<td>Days&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Stage</td>
<td>Days</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>Bud</td>
<td>35</td>
<td>Bud</td>
<td>21</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>Bud</td>
<td>35</td>
<td>Flower</td>
<td>35</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>Flower</td>
<td>21</td>
<td>Flower</td>
<td>21</td>
</tr>
</tbody>
</table>

<sup>a</sup>No reproductive stage was reached in this treatment.

<sup>b</sup>Specified reproductive stage was reached after cut plants were placed in growth chamber.
but Hermes II reached the reproductive stages later than Arlington did.

Analysis of covariance by using stage of maturity as a covariable confirmed that Arlington had fewer tillers than Hermes II (P<0.05; data not shown). The other variables did not differ between cultivars, however (P>0.05; data not shown). Thus, tiller number was the only variable that was inherently different between cultivars in this study.

There were significant cultivar by daylength interactions for stage of maturity, plant height, and tiller number (Table 13). Arlington increased 49% in mean stage value from 10-h to 20-h daylengths, whereas Hermes II only increased 13%. This indicates that Arlington has a shorter critical photoperiod than Hermes II. Plant height increased more for Arlington than for Hermes II from 10-h to 20-h daylengths, although the changes were not as large as in stage of maturity (41 vs. 22%, respectively). Pulli (1988) reported that southern cultivars of red clover were taller than northern types up to 16-h daylength, beyond which no difference in plant height was observed. Tiller number decreased 5% between 10- and 20-h daylengths for Arlington, but increased 10% for Hermes II. Pulli (1988) reported that tiller number decreases as daylength increases because plants induce apical dominance. Results from this study suggest that Hermes II has less apical dominance than Arlington, which may be an adaptation to better winter survival.

There were significant cultivar by temperature interactions for stage of maturity and tiller number (Figs. 8 and 9), whereas plant height, leaf area, and SLW were not significant (P>0.05; data not shown). A 10 °C increase influenced maturity stages of Arlington more than they did for Hermes II (Fig. 8). This indicates that Hermes II is less affected by temperature than Arlington. The daylength by temperature by cultivar interaction also was significant (P<0.0023; data not shown). Hermes II had approximately the same MSC values at 10-h daylength and 10 °C, but as daylengths and temperature increased, daylength influenced MSC values more than temperature (Figs. 8 and 10). Conversely, temperature
Table 13. Daylength and cultivar effects on morphological characteristics for two red clover cultivars, Arlington and Hermes II

<table>
<thead>
<tr>
<th>Daylength</th>
<th>Cv&lt;sup&gt;a&lt;/sup&gt;</th>
<th>MSC&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Height cm</th>
<th>Tillers no. pot&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Leaf area cm&lt;sup&gt;2&lt;/sup&gt; pot&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SLW&lt;sup&gt;c&lt;/sup&gt; g m&lt;sup&gt;-2&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>A</td>
<td>25.0</td>
<td>16.6</td>
<td>50.3</td>
<td>731</td>
<td>43.0</td>
</tr>
<tr>
<td>15</td>
<td>A</td>
<td>30.7</td>
<td>20.9</td>
<td>49.7</td>
<td>1012</td>
<td>47.7</td>
</tr>
<tr>
<td>20</td>
<td>A</td>
<td>37.3</td>
<td>23.4</td>
<td>47.6</td>
<td>1117</td>
<td>53.8</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>31.0</td>
<td>20.3</td>
<td>49.2</td>
<td>953</td>
<td>48.17</td>
</tr>
<tr>
<td>10</td>
<td>H</td>
<td>25.7</td>
<td>16.4</td>
<td>46.8</td>
<td>631</td>
<td>46.3</td>
</tr>
<tr>
<td>15</td>
<td>H</td>
<td>24.7</td>
<td>17.5</td>
<td>50.7</td>
<td>891</td>
<td>50.2</td>
</tr>
<tr>
<td>20</td>
<td>H</td>
<td>29.0</td>
<td>20.0</td>
<td>51.7</td>
<td>1144</td>
<td>54.7</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>26.5</td>
<td>18.0</td>
<td>49.7</td>
<td>889</td>
<td>50.40</td>
</tr>
</tbody>
</table>

Gr. mean<sup>d</sup> 22.8 15.4 49.8 1,001 50.83

<table>
<thead>
<tr>
<th></th>
<th>SEa&lt;sup&gt;e&lt;/sup&gt;</th>
<th>SEb&lt;sup&gt;f&lt;/sup&gt;</th>
<th>P&gt;F&lt;sup&gt;g&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.1</td>
<td>0.5</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>2.9</td>
<td>0.6</td>
<td>0.0348</td>
</tr>
<tr>
<td></td>
<td>6.3</td>
<td>1.1</td>
<td>0.0250</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>29</td>
<td>0.5201</td>
</tr>
<tr>
<td></td>
<td>3.1</td>
<td>1.3</td>
<td>0.4551</td>
</tr>
</tbody>
</table>

<sup>a</sup>A=Arlington; H=Hermes II.
<sup>b</sup>Mean stage value based on mean stage by count.
<sup>c</sup>Specific leaf area.
<sup>d</sup>Overall mean of cultivars.
<sup>e</sup>Standard error of a daylength mean (5 df).
<sup>f</sup>Standard error of a cultivar mean (429 df).
<sup>g</sup>Probability for a larger F-value for the daylength by cultivar interaction.
Figure 8. Mean stage by count values for two red clover cultivars at two temperatures. Each cultivar mean is based on 126 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by temperature interaction was significant at $P=0.0001$. 

Mean stage by count

Temperature (°C)

Arlington  SE=5.6
Hermes II
Figure 9. Tiller number for two red clover cultivars at two temperatures. Each cultivar mean is based on 126 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by temperature interaction was significant at P=0.0022.
Figure 10. Regressions of mean stage by count values for two red clover cultivars on daylength. Data regressed were averages of replications, temperatures, and harvests (n=84). SE=Square root of the residual mean square of a cultivar mean. The cultivar by daylength interaction was significant at P=0.0001.
influenced stage of maturity more at the shorter daylengths for Arlington (Figs. 8 and 10).

Tiller number of Arlington decreased more than for Hermes II as the temperature increased by 10 °C (Fig. 9). One possible explanation for the larger decrease in tiller number in Arlington is that Arlington has stronger apical dominance than Hermes II.

There was a significant cultivar by harvest interaction for stage of maturity (Fig. 11), whereas the interaction was not significant for any of the other morphological characteristics (P>0.05; data not shown). The ranges of daylengths and temperatures obviously affected Arlington more than Hermes II in this study.
Figure 11. Regressions of mean stage by count values on harvest for two red clover cultivars. Data from each cultivar were regressed on a mean value from replications, experiments, daylengths, and temperatures. SE=Square root of mean square lack of fit from cultivar by harvest interaction. The cultivar by harvest interaction was significant at P=0.0042
Growth characteristics

Growth of root, shoot, and leaf as well as their combined weights (total weight) will be discussed with respect to daylength, temperature, cultivar, and harvest.

Daylength and daylength interactions Weights of all plant parts and total weight increased with daylength (Table 14). Using the 10-h daylength as a reference, total weight increased 39 and 68% at 15- and 20-h daylengths, respectively. However, shoot weight increased more than leaf weight and leaf weight increased more than root weight with increased daylength. Furthermore, shoot weight increased relatively more than root weight while percentage leaf as a portion of total weight remained constant over daylengths.

Root weight increased over time and increased with increasing daylength (Fig. 12). The rate of increase in root weight was lowest at the 10-h daylength and highest at the 15-h daylength. These results suggest that root weight is not stimulated beyond a 15-h daylength. Pulli (1988) reported that red clover of Swedish and Finnish origin increased in root weight at diminishing rates between 16- and 20-h daylengths, findings which support the results in this study.

Shoot and leaf weights increased over harvests and with increasing daylength (Figs. 13 and 14). The absolute shoot growth rates over harvests increased in approximately equal proportions for the three daylengths, whereas leaf rates were slightly higher at 15-h than at 20-h daylength.

Leaf:stem ratios revealed that shoots were produced at the expense of leaves over all harvests at the 20-h daylength, whereas the opposite was true for plants grown at the 10-h daylength up to harvest 6. Leaf:stem ratios at 15 h remained relatively constant until harvest 5 when they started to decrease (Fig. 15). Figure 15 also shows that leaf:stem ratios were higher with increased daylength at the initial two harvests, indicating that long days favor leaf growth over shoot growth at early maturity stages. Thereafter, daylength acted to increase the rate of
Table 14. Daylength effects on growth of red clover plant-parts

<table>
<thead>
<tr>
<th>Daylength</th>
<th>Total weight</th>
<th>Root weight</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S</th>
<th>S:R</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>g pot⁻¹</td>
<td>g pot⁻¹</td>
<td>%</td>
<td>g pot⁻¹</td>
<td>%</td>
<td>g g⁻¹</td>
</tr>
<tr>
<td>10</td>
<td>13.6</td>
<td>5.1</td>
<td>38</td>
<td>4.6</td>
<td>34</td>
<td>3.9</td>
</tr>
<tr>
<td>15</td>
<td>18.9</td>
<td>7.1</td>
<td>38</td>
<td>6.4</td>
<td>34</td>
<td>5.5</td>
</tr>
<tr>
<td>20</td>
<td>22.8</td>
<td>7.3</td>
<td>32</td>
<td>8.9</td>
<td>39</td>
<td>6.6</td>
</tr>
<tr>
<td>Mean</td>
<td>18.4</td>
<td>6.5</td>
<td>36</td>
<td>6.6</td>
<td>36</td>
<td>5.3</td>
</tr>
</tbody>
</table>

SEₐ      2.7       0.8       1.6       0.5          0.07 0.08
P>Fₐ   0.0674  0.1287  0.0366  0.0095  0.4940  0.0313

ₐ Root % is calculated as root weight divided by total weight.
ₐ Leaf:Stem ratio on a weight basis.
ₐ Shoot:Root ratio on a weight basis.
ₐ Standard error of a daylength mean (5 df).
ₐ Probability of a larger F-value for the daylength effects.
Figure 12. Regressions of root weight on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0124.
Figure 13. Regressions of shoot weight on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0001
Figure 14. Regressions of leaf weight on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at $P=0.0105$. 

\[ Y_{10} = -0.040 + 0.867H \quad R^2=0.91 \quad SE=0.582 \]

\[ Y_{15} = 0.446 + 1.118H \quad R^2=0.95 \quad SE=0.517 \]

\[ Y_{20} = 1.657 + 1.100H \quad R^2=0.92 \quad SE=0.659 \]
Figure 15. Regressions of leaf:stem ratios on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0001
maturation of plants with the result of favoring shoot growth over leaf growth. These results agree with findings by Deinum et al. (1981).

The shoot:root ratio increased over harvests and increased with daylength (Fig. 16). Whereas the shoot:root ratio was approximately the same at 10-h and 15-h daylengths, it was higher at the 20-h daylength. This was probably a result of little or no stimulation of root growth beyond the 15-h daylength. Results from previous reports also suggest that long days favor shoot growth over root growth (Chapin, 1980).

**Temperature and temperature interactions**

A temperature increase of 10 °C reduced root weight by 14%, but increased shoot, leaf, and total weight by 29, 4, and 6%, respectively (Table 15). Shoot weight also increased relatively more than root weight as temperature increased while proportion of leaf weight remained constant (Table 15). It should be noted, however, that the effect of daylength was greater than the effect of temperature for all weights (Tables 14 and 15).

There were significant temperature by harvest interactions for shoot and leaf weights (Figs. 17 and 18), whereas there was no significant interaction for root weight (P>0.0972; data not shown). Shoot weight was higher at 20 °C and increased at a higher rate than plants grown at 10 °C (Fig. 17). The interaction was not significant after adjustment for stage of maturity (data not shown), indicating that shoot weight increased as a result of more rapid development at 20 °C. Leaf weight initially was higher at 20 °C, but after harvest 5 leaf weight was higher at 10 °C (Fig. 18). The switch in leaf weight occurred at the same time as stage of maturity plateaued at 20 °C (Fig. 4). Maturation ceased when reproductive stages were reached and when leaf loss and senescence occurred.

At 20 °C, the leaf:stem ratio decreased linearly throughout the sampling period, whereas it increased curvilinearly at 10 °C up to harvest 5 and then decreased at the final harvests (Fig. 19). Reproductive development was delayed at 10 °C, which allowed for more leaf than shoot growth.
Figure 16. Regressions of shoot:root ratios on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at $P=0.0001$. 

Regression equations and $R^2$ values for each daylength:

- **10 h**: $Y_{10} = 0.751 + 0.077H - 0.006H^2$  
  $R^2 = 0.17$  
  SE = 0.127

- **15 h**: $Y_{15} = 1.116 - 0.152H + 0.022H^2$  
  $R^2 = 0.80$  
  SE = 0.070

- **20 h**: $Y_{20} = 0.628 + 0.222H - 0.016H^2$  
  $R^2 = 0.73$  
  SE = 0.118
Table 15. Temperature effects on growth of red clover plant-parts

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Total weight</th>
<th>Root weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S:R&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>18.0</td>
<td>7.0</td>
<td>40</td>
<td>5.8</td>
<td>32</td>
<td>5.2</td>
</tr>
<tr>
<td>20</td>
<td>19.0</td>
<td>6.0</td>
<td>33</td>
<td>7.5</td>
<td>38</td>
<td>5.4</td>
</tr>
<tr>
<td>Mean</td>
<td>18.5</td>
<td>6.5</td>
<td>37</td>
<td>6.7</td>
<td>35</td>
<td>5.3</td>
</tr>
<tr>
<td>SE&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.4</td>
<td>0.8</td>
<td>1.4</td>
<td>0.4</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.7080</td>
<td>0.2676</td>
<td>0.2834</td>
<td>0.7029</td>
<td>0.1690</td>
<td>0.0031</td>
</tr>
</tbody>
</table>

<sup>a</sup>Root % is calculated as root weight divided by total weight.

<sup>b</sup>Leaf:Stem ratio on a weight basis.

<sup>c</sup>Shoot:Root ratio on a weight basis.

<sup>d</sup>Standard error of a temperature mean (5 df).

<sup>e</sup>Probability of a larger F-value for the temperature effects.
Figure 17. Regressions of shoot weight on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0210.
Figure 18. Regressions of leaf weight on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0005.
Figure 19. Regressions of leaf:stem ratios on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at $P=0.0001$. 

- **10°C**: $Y_{10} = 0.354 + 0.288H - 0.030H^2$  
  $R^2=0.86$ SE=0.047
- **20°C**: $Y_{20} = 1.009 - 0.035H$  
  $R^2=0.75$ SE=0.042
The shoot:root ratio remained relatively constant over time at 10 °C, whereas it initially increased followed by a plateau at 20 °C (Fig. 20). Heide et al. (1985) reported that increased maturity of plants by means of increased temperatures or daylengths increases the shoot:root ratio.

**Cultivar and cultivar interactions** Arlington had higher shoot:root ratio, total-, shoot-, and leaf weight than Hermes II (Table 16). Hermes II had higher root weight and leaf:stem ratio, however (Table 16). Analysis of covariance confirmed that differences in weight and leaf:stem ratio were caused by maturity differences between cultivars (data not shown). It is apparent that Arlington partitioned more weight into shoots than Hermes II while Hermes II partitioned more weight into roots than Arlington. Both cultivars partitioned an equal proportion of photosynthate into leaves, however. Thus, the Swedish cultivar produces relatively more root growth than its American counterpart, indicating that Hermes II is more winter hardy. This conclusion does not agree with findings of Pulli (1988), who indicated that northern cultivars of red clover had lower root weights than southern cultivars. Cultivar effects on leaf and shoot weight were consistent with results of Pulli (1988), however.

There were significant cultivar by daylength interactions for shoot and root weights (Figs. 21 and 22), whereas there was no interaction for leaf weight (data not shown). Shoot weight for Arlington increased more over daylengths than they did for Hermes II. Conversely, root weight was more stimulated by daylength in Hermes II than in Arlington. Because of the opposite responses of shoot and root weight to daylength, the cultivar by daylength interaction for shoot:root ratio also was significant (Fig. 23).

Leaf weight and leaf:stem ratio were the only components affected differently by temperature in the two cultivars. Leaf weight for Arlington remained constant as the temperature increased while leaf weight for Hermes II increased (Fig. 24). Therefore, it appears that Arlington starts producing leaves at a lower
Figure 20. Regressions of shoot:root ratios on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0001.
Table 16. Cultivar effects on growth of red clover plant-parts

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Total weight</th>
<th>Root weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S:R&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g g&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Arlington</td>
<td>18.8</td>
<td>6.3</td>
<td>34</td>
<td>7.0</td>
<td>37</td>
<td>5.5</td>
</tr>
<tr>
<td>Hermes II</td>
<td>18.2</td>
<td>6.7</td>
<td>37</td>
<td>6.3</td>
<td>35</td>
<td>5.2</td>
</tr>
<tr>
<td>Mean</td>
<td>18.5</td>
<td>6.5</td>
<td>36</td>
<td>6.7</td>
<td>36</td>
<td>5.4</td>
</tr>
<tr>
<td>SE&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
<td>0.2</td>
<td>0.02</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.4450</td>
<td>0.0514</td>
<td>0.0165</td>
<td>0.1042</td>
<td>0.0043</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup>Root % is calculated as root weight divided by total weight.

<sup>b</sup>Leaf:Stem ratio on a weight basis.

<sup>c</sup>Shoot:Root ratio on a weight basis.

<sup>d</sup>Standard error of a cultivar mean (429 df).

<sup>e</sup>Probability of a larger F-value for the cultivar effects.
Figure 21. Shoot weight effect for two red clover cultivars at three daylengths. Each cultivar mean is based on 84 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by daylength interaction was significant at P=0.0065
Figure 22. Root weight effect for two red clover cultivars at three daylengths. Each cultivar mean is based on 84 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by daylength interaction was significant at $P=0.0496$.
Figure 23. Shoot:root ratio effect for two red clover cultivars at three daylengths. Each cultivar mean is based on 84 observations. SE=Squareroot of the residual mean square of a cultivar mean. The cultivar by daylength interaction was significant at P=0.0001.
Figure 24. Leaf weight effect for two red clover cultivars at two temperatures. Each cultivar mean is based on 126 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by temperature interaction was significant at P=0.0232.
temperature than Hermes II. The leaf:stem ratio was higher and decreased less for Hermes II than for Arlington as the temperature increased 10 °C (Fig. 25). These differences between cultivars were likely caused both by maturity differences and the ability of Hermes II to produce relatively more root than shoot dry matter.
Figure 25. Leaf:stem ratio effect for two red clover cultivars at two temperatures. Each cultivar mean is based on 126 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by temperature interaction was significant at P=0.0073.
Quality characteristics

Total N and IVDMD were studied with respect to daylength, temperature, cultivars and harvests and their interactions.

Daylength and daylength interactions  Total N concentration decreased 22% as daylength increased from 10 h to 20 h (Table 17). Total N concentrations increased over time and rates of increase were similar for the three daylengths (Fig. 26). The lower concentrations of N at the longer days is likely an effect of higher growth rates, which resulted in dilution of N in leaf and shoot tissues.

Average IVDMD concentrations were not significantly affected by daylength (Table 17). Figure 27, however, shows that IVDMD concentrations decreased over time at the 20-h daylength, whereas they increased at both 10-h and 15-h daylengths. Leaf:stem ratios decreased over time at 20 h, remained relatively constant at 15 h, and increased over time at 10-h daylengths. Because leaves are more digestible than stems (Brignall et al., 1989), an increased leaf:stem ratio would be expected to increase IVDMD concentrations. Furthermore, new and less mature tillers were formed at the shorter daylengths while advancement of maturity lagged, which may explain why concentrations were higher at the shorter days.

Temperature and temperature interactions  Total N concentrations remained constant, whereas IVDMD concentrations decreased as the temperature increased 10 °C (Table 18). Daylength had the greatest effect on total N, whereas temperature had a much larger effect on IVDMD concentrations (Tables 17 and 18).

Total N concentrations increased more over time at 10 °C than at 20 °C (Fig. 28). Growth progressed more slowly at 10 °C, and therefore, N concentrations were not as much diluted as they were at 20 °C. In harvest 2, plants had higher N concentrations at 20 °C than at 10 °C. As explained in the growth study section, this was because leaf growth was initially favored over stem growth, but at later harvests, stem growth was favored over leaf growth. Leaves are known to have
Table 17. Daylength effects on forage quality characteristics averaged over two red clover cultivars

<table>
<thead>
<tr>
<th>Daylength (h)</th>
<th>IVDMD(^a)</th>
<th>N(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>664</td>
<td>46</td>
</tr>
<tr>
<td>15</td>
<td>665</td>
<td>41</td>
</tr>
<tr>
<td>20</td>
<td>657</td>
<td>36</td>
</tr>
<tr>
<td>Mean</td>
<td>662</td>
<td>41</td>
</tr>
<tr>
<td>SE(^a)</td>
<td>15.6</td>
<td>2.7</td>
</tr>
<tr>
<td>P&gt;F(^d)</td>
<td>0.8758</td>
<td>0.0389</td>
</tr>
</tbody>
</table>

\(^a\) *In vitro* dry matter digestibility.

\(^b\) Total Kjeldahl nitrogen.

\(^c\) Standard error of a daylength mean

\(^d\) Probability of a larger F-value for daylength effects.
Figure 26. Regressions of total nitrogen (N) concentrations on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at $P=0.1000$
Figure 27. Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for three daylength treatments of red clover. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0001
Table 18. Temperature effects on forage quality characteristics averaged over two red clover cultivars.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>IVDMD^a</th>
<th>N^b</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>689</td>
<td>41</td>
</tr>
<tr>
<td>20</td>
<td>635</td>
<td>41</td>
</tr>
<tr>
<td>Mean</td>
<td>662</td>
<td>41</td>
</tr>
</tbody>
</table>

SE^c = 12.7, SE^d = 2.2, P>F = 0.0072, 0.8315

\(^a\) In vitro dry matter digestibility.
\(^b\) Total Kjeldahl nitrogen
\(^c\) Standard error of a temperature mean (5 df).
\(^d\) Probability of a larger F-value for temperature effects.
Figure 28. Regressions of total nitrogen (N) concentrations on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0077.
higher N-concentrations than stems (Kalu and Fick, 1981).

The IVDMD concentrations increased at a higher rate at 10 °C than at 20 °C, which is likely caused by the higher growth rates at 20 °C (Fig. 29). Plants at 20 °C also were more mature and had more stem relative to leaf, which caused IVDMD concentrations to decrease. Surprisingly IVDMD concentrations increased over time at both temperatures; IVDMD concentrations normally decrease over time because of advancement in maturity. The increase in IVDMD concentration was likely caused by continuous tiller formation because tiller number did not reach an equilibrium in this study. Thus, new and less mature tillers kept the IVDMD concentrations at a high level.

Cultivar and cultivar interactions Hermes II had higher total N and IVDMD concentrations than Arlington (Table 19). The differences between cultivars were likely caused by the higher leaf:stem ratios of Hermes II. Maturity differences seemed to play less of a role because adjustment for stage of maturity did not change ranking of the cultivars. Digestibility of Arlington decreased more with a 10- °C increase than that of Hermes II (Fig. 30). This was a result of Arlington being more mature (data not shown). Hermes II had higher N concentrations than Arlington, but the change in N did not differ between cultivars as the temperature increased (data not shown).
Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for two temperature treatments of red clover. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0084.
Table 19. Cultivar effects on forage quality characteristics averaged over two red clover cultivars, Arlington and Hermes II

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>IVDMD&lt;sup&gt;a&lt;/sup&gt;</th>
<th>N&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlington</td>
<td>659</td>
<td>40</td>
</tr>
<tr>
<td>Hermes II</td>
<td>666</td>
<td>42</td>
</tr>
<tr>
<td>Mean</td>
<td>663</td>
<td>41</td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.5</td>
<td>0.4</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0055</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup> In vitro dry matter digestibility.
<sup>b</sup> Total Kjeldahl nitrogen.
<sup>c</sup> Standard error of a cultivar mean (429 df).
<sup>d</sup> Probability of a larger F-value for cultivar effects.
Figure 30. *In vitro* dry matter digestibility (IVDMD) concentration effects for two red clover cultivars on temperature. Each cultivar mean is based on 126 observations. SE=Square root of the residual mean square of a cultivar mean. The cultivar by temperature interaction was significant at P=0.0037.
Morphological characteristics

The effects of daylength, temperature, cultivar, and harvest on stage of maturity, plant height, tiller number, leaf area, and specific leaf weight will be discussed in this section.

Daylength and daylength interactions Stage of maturity, plant height, tiller number, leaf area, and specific leaf weight increased 12, 17, 13, 46, and 4%, respectively when daylength increased from 10 h to 20 h (Table 20). Except for specific leaf weight, most of the stimulation occurred between 10 h and 15 h. Stage of maturity, for example, increased 1.5 times more between 10 h and 15 h than between 15 h and 20 h. Julén (1977) reported that the critical photoperiod for timothy ranged between 13 and 16 h. Thus, the critical photoperiod for timothy in this study appeared to be in the lower range of that reported.

Stage of maturity increased curvilinearly over harvests and the increase was different for the three daylengths (Fig. 31). Plants grown at 20 h reached a plateau at stage 29. Plants grown at 15 h initially lagged two weeks behind in development compared with those grown at 20 h. At harvest 5, the lag had decreased to one week and at harvest 7, stage of maturity was approximately the same for plants grown at 15 h and 20 h. Plants grown at the 10-h daylength showed a marginal increase in maturity over time. Mitchell (1987) reported that growth rates decreased when smooth bromegrass reached reproductive development. Although observed mean stage values indicated that plants grown at 20-h were in the ninth leaf stage, many plants had reached heading stages. New tillers also contributed to the low mean stage values.

Plant height increased linearly over time and increased with increasing daylength (Fig. 32). Plant height at the 10-h daylength increased at approximately half the rate compared with plants grown at 15 and 20-h daylengths.
Table 20. Daylength effects on morphological characteristics averaged over two timothy cultivars

<table>
<thead>
<tr>
<th>Daylength</th>
<th>MSC(^a)</th>
<th>Height</th>
<th>Tillers</th>
<th>Leaf area</th>
<th>SLW(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td></td>
<td>cm</td>
<td>no. pot(^{-1})</td>
<td>cm(^2) pot(^{-1})</td>
<td>g m(^{-2})</td>
</tr>
<tr>
<td>10</td>
<td>24.3</td>
<td>26.5</td>
<td>103.3</td>
<td>740</td>
<td>56.7</td>
</tr>
<tr>
<td>15</td>
<td>26.0</td>
<td>32.7</td>
<td>114.2</td>
<td>1100</td>
<td>55.5</td>
</tr>
<tr>
<td>20</td>
<td>27.1</td>
<td>30.9</td>
<td>116.7</td>
<td>1077</td>
<td>59.0</td>
</tr>
<tr>
<td>Mean</td>
<td>25.8</td>
<td>30.0</td>
<td>111.4</td>
<td>972</td>
<td>57.1</td>
</tr>
<tr>
<td>SE(^a)</td>
<td>0.6</td>
<td>2.0</td>
<td>6.3</td>
<td>85</td>
<td>19.0</td>
</tr>
<tr>
<td>P&gt;F(^d)</td>
<td>0.0131</td>
<td>0.0553</td>
<td>0.2100</td>
<td>0.0509</td>
<td>0.5613</td>
</tr>
</tbody>
</table>

\(^a\)Mean stage value based on mean stage by count.
\(^b\)Specific leaf weight.
\(^c\)Standard error of a daylength mean (5 df).
\(^d\)Probability of a larger F-value for daylength effects.
Regressions of mean stage by count values for three daylength treatments of timothy on harvest. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE = Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at $P=0.0010$
Figure 32. Regressions of plant height for three daylength treatments of timothy on harvest. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0040.
Temperature and temperature interactions

Stage of maturity, plant height, and leaf area increased 9, 34, and 56%, respectively with a 10 °C increase in temperature, whereas tiller number and specific leaf weight decreased 11 and 20%, respectively (Table 21). Increased temperatures, within an optimum range, are known to advance maturity and to stimulate plant height and leaf area (Deinum et al., 1981; Heide et al., 1985; Pulli, 1988). As leaf area increased at the higher temperature, specific leaf weight decreased, which indicates that metabolism of photosynthate occurs more rapidly. Furthermore, temperature had a larger effect on the morphological characteristics than daylength did (Tables 20 and 21).

Stage of maturity increased curvilinearly over time and increased with increasing temperature. (Fig. 33). Plants grown at 10 °C lagged in maturity compared with plants grown at 20 °C, indicating that increased temperature stimulates advancement of maturity. Temperature also had a larger effect on maturity than daylength over the 7-week period, indicating that timothy may be less influenced by daylength than by temperature (Figs. 31 and 33).

Plant height increased curvilinearly over time and increased at increasing temperature (Fig. 34). Plant height at 10 °C remained relatively constant up to harvest 4 when it increased. Height of plants grown at 20 °C increased throughout the study, however. Unlike the daylength by harvest interaction, in which height changed linearly over time, plant height changed quadratically over time in the temperature treatments (Figs. 32 and 34). These results imply that daylength provides the fuel for the plant to increase in height, whereas temperature acts as the modulator.

Cultivar and cultivar interactions

Timfor was more mature, had more tillers, and higher leaf areas, but lower specific leaf weight than Kämpe II. Plant height was not different between the cultivars, however (Table 22). Previous reports have shown that southern cultivars mature more quickly and have higher leaf areas than northern ones when grown under similar environmental conditions.
Table 21. Temperature effects on morphological characteristics averaged over two timothy cultivars

<table>
<thead>
<tr>
<th>Temperature</th>
<th>MSC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Height</th>
<th>Tillers</th>
<th>Leaf area</th>
<th>SLW&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>cm</td>
<td>no. pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>cm&lt;sup&gt;2&lt;/sup&gt; pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>24.7</td>
<td>25.7</td>
<td>117.9</td>
<td>761</td>
<td>63.4</td>
</tr>
<tr>
<td>20</td>
<td>26.9</td>
<td>34.4</td>
<td>105.0</td>
<td>1184</td>
<td>50.7</td>
</tr>
<tr>
<td>Mean</td>
<td>25.8</td>
<td>30.1</td>
<td>111.5</td>
<td>973</td>
<td>57.1</td>
</tr>
</tbody>
</table>

SE<sup>c</sup> 0.5 1.6 5.2 69 3.6  
P>F<sup>d</sup> 0.0085 0.0029 0.0703 0.0077 0.0416

<sup>a</sup>Mean stage value based on mean stage by count.  
<sup>b</sup>Specific leaf weight.  
<sup>c</sup>Standard error of a temperature mean (5 df).  
<sup>d</sup>Probability of a larger F-value for temperature effects.
Figure 33. Regressions of mean stage by count values on harvest for two temperature treatments of timothy. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0275.
Figure 34. Regressions of plant height on harvest for two temperature treatments of timothy. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at $P=0.0001$. 

\[ Y_{10} = 34.157 - 6.363H + 0.671H^2 \quad R^2=0.91 \quad SE=1.513 \]

\[ Y_{20} = 19.242 + 5.682H - 0.450H^2 \quad R^2=0.90 \quad SE=1.499 \]
Table 22. Cultivar effects on morphological characteristics for Timfor and Kämpe II timothy

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSC&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Height</th>
<th>Tillers</th>
<th>Leaf area</th>
<th>SLW&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>no. pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>cm&lt;sup&gt;2&lt;/sup&gt; pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g m&lt;sup&gt;-2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Timfor</td>
<td>26.7</td>
<td>30.0</td>
<td>120.2</td>
<td>1049</td>
<td>56.5</td>
</tr>
<tr>
<td>Kämpe II</td>
<td>24.9</td>
<td>30.1</td>
<td>102.6</td>
<td>895</td>
<td>57.6</td>
</tr>
<tr>
<td>Mean</td>
<td>25.8</td>
<td>30.1</td>
<td>111.4</td>
<td>972</td>
<td>57.1</td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.3</td>
<td>0.5</td>
<td>4.1</td>
<td>47</td>
<td>1.3</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.7477</td>
<td>0.0001</td>
<td>0.0209</td>
<td>0.0769</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage value based on mean stage by count.

<sup>b</sup>Specific leaf weight.

<sup>c</sup>Standard error of a cultivar mean (429 df).

<sup>d</sup>Probability of a larger F-value for cultivar effects.
(Pulli, 1988; Julén, 1977). Therefore, it was no surprise that Timfor was more mature, taller, and had a higher leaf area. Results of leaf area and specific leaf weight were reversed when adjusted for stage of maturity, indicating that effects of leaf area and specific leaf weight were related to maturity differences rather than other genetic differences between the cultivars (P<0.05; data not shown).

Surprisingly, Timfor had more tillers than Kämpe II, however. Pulli (1988) stated that northern cultivars generally have more tillers than southern ones as a mean to protect themselves from long and harsh winters.

There was a significant cultivar by daylength interaction for stage of maturity only (P<0.03; data not shown). Both cultivars increased in maturity over daylengths, but Timfor increased more than Kämpe II between 10 and 15 h, whereas Kämpe II increased more than Timfor between 15 and 20 h. This indicates that Timfor has a lower critical photoperiod than Kämpe II to induce flowering. Furthermore, advancement of maturity was reached earlier for Timfor between 10-h and 15-h daylengths, whereas Kämpe II was earlier between 15- and 20-h daylengths (Table 23).
Table 23. Highest reproductive stage (up to flowering) for 'Timfor' and 'Kämpe II' timothy after specified number of days in each daylength and temperature treatment

<table>
<thead>
<tr>
<th>Daylength</th>
<th>Temperature °C</th>
<th>Timfor Stage</th>
<th>Days&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Kämpe II Stage</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td></td>
<td>a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td></td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>Boot</td>
<td>42</td>
<td>Boot</td>
<td>49</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td></td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>15</td>
<td>20</td>
<td>Flower</td>
<td>49</td>
<td>Boot</td>
<td>49</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>Flower</td>
<td>49</td>
<td>Flower</td>
<td>42</td>
</tr>
</tbody>
</table>

<sup>a</sup>No reproductive stage was reached in this treatment.
<sup>b</sup>Specified reproductive stage was reached after cut plants were placed in growth chamber.
Growth characteristics

Growth of root, shoot, and leaf as well as their combined weights (total weight) will be discussed with respect to daylength, temperature, cultivar, and harvest.

Daylength and daylength interactions

Weight of all plant parts and total weight increased 38 to 54% between 10-h and 15-h daylengths. Shoot weight increased further between 15-h and 20-h daylengths, whereas total weight, root weight, and leaf weight either plateaued or decreased in weight (Table 24). When weights of plant parts were calculated as a percentage of total weight, there was a tendency for shoot weight to increase relatively more than root weight, whereas leaf weight remained relatively constant for the three daylengths (Table 24). Furthermore, leaf:stem ratios decreased with increased daylength. The shoot:root ratio was lowest at 15 h as a result of a high root weight (Table 24). None of the daylength effects were significant when weights were adjusted for stage of maturity, suggesting that increased photosynthetic energy levels act mainly by advancing maturity of timothy (data not shown).

There was a significant daylength by harvest interaction for root weight (Fig. 35). Root weight increased linearly over time for timothy grown at 15- and 20-h daylengths. Root weight at 15 h was higher than that at 20 h over all harvests. Root weight was lowest at 10-h and it increased curvilinearly over time. Root weight initially lagged, but increased after harvest 4 for timothy grown at 10 h. Thus, it appears that daylengths beyond 15 h had a detrimental effect on root growth. It also appeared that root reserves were used between harvest 1 and 4 to produce leaves and shoots at the 10-h daylength.

Leaf weight increased curvilinearly over time, but at different rates at the three daylengths (Fig. 36). Leaf weight was higher at 20- than at 15-h daylengths until harvest 5 at which time leaf weights at 15 h were higher. This was probably a result of senescence and drop of leaves for plants grown at 20-h daylength, which
Table 24. Daylength effects on growth of timothy plant-parts

<table>
<thead>
<tr>
<th>Daylength</th>
<th>Total weight</th>
<th>Root weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S:R&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>g pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g pot&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g g&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>16.1</td>
<td>7.4</td>
<td>46</td>
<td>3.9</td>
<td>24</td>
<td>4.9</td>
</tr>
<tr>
<td>15</td>
<td>23.8</td>
<td>11.4</td>
<td>48</td>
<td>5.4</td>
<td>23</td>
<td>7.0</td>
</tr>
<tr>
<td>20</td>
<td>23.4</td>
<td>10.4</td>
<td>44</td>
<td>6.1</td>
<td>26</td>
<td>6.9</td>
</tr>
<tr>
<td>Mean</td>
<td>21.1</td>
<td>9.7</td>
<td>46</td>
<td>5.1</td>
<td>24</td>
<td>6.3</td>
</tr>
<tr>
<td>SE&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.5</td>
<td>1.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.07</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.0146</td>
<td>0.1174</td>
<td>0.0161</td>
<td>0.0085</td>
<td>0.1430</td>
<td>0.3963</td>
</tr>
</tbody>
</table>

<sup>a</sup>Root % is calculated as root weight divided by total weight.

<sup>b</sup>Leaf:Stem ratio on a weight basis.

<sup>c</sup>Shoot:Root ratio on a weight basis.

<sup>d</sup>Standard error of a daylength mean (5 df).

<sup>e</sup>Probability of a larger F-value for the daylength effects.
Figure 35. Regressions of root weight on harvest for three daylength treatments of timothy. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0299.
Figure 36. Regressions of leaf weight on harvest for three daylength treatments of timothy. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0255
appeared to be water-stressed. Leaf weight was lowest at 10-h and lagged in weight until harvest 4, indicating that photosynthetic energy was not sufficient to provide rapid leaf growth.

Shoot weight increased linearly over time and increased with increasing daylength (Fig. 37). Shoot weight increased approximately 1.5 times faster for plants grown at 15 h and 20 h compared with plants grown at 10-h daylengths. Thus, daylength stimulated shoot weight more than root and leaf weight. The daylength by harvest interaction for shoot weight was caused by maturity differences between the daylength treatments (data not shown).

The leaf:stem ratios increased over time at 10 h, decreased at 20 h, and remained constant at 15-h daylength (Fig. 38). At harvest 2, the leaf:stem ratio was highest at 15 h and lowest at 10 h, indicating that at daylengths up to 15 h leaf growth is relatively more stimulated than shoot growth. As time progressed, however, stem production was relatively more favored than leaf production at the longer days.

**Temperature and temperature interactions** Total, shoot, and root weight decreased 4, 6, and 13%, respectively with a 10 °C-increase in temperature, whereas leaf weight increased 14% (Table 25). The leaf:stem ratio increased 34% with a 10 °C increase in temperature. This was surprising because leaf:stem ratios normally decrease with increased temperature. The increased leaf:stem ratio probably was a result of stress. Plants grown at 20 °C appeared water-stressed, even though they were watered once to twice daily. As a proportion of total weight, root weight decreased, shoot weight remained constant, and leaf weight increased as the temperature increased 10 °C. Thus, leaf weight was produced at the expense of root weight with increasing temperature, although the effect of temperature was relatively small in this study. There was no significant temperature by harvest interaction for any of the weights in this study (P>0.05; data not shown).
Figure 37. Regressions of shoot weight on harvest for three daylength treatments of timothy. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at $P=0.0394$. 

\[
egin{align*}
10 \text{ h} & : Y_{10} = 0.008 + 0.854H \quad R^2=0.61 \quad SE=1.416 \\
15 \text{ h} & : Y_{15} = 0.195 + 1.240H \quad R^2=0.90 \quad SE=0.856 \\
20 \text{ h} & : Y_{20} = 0.057 + 1.337H \quad R^2=0.99 \quad SE=0.258
\end{align*}
\]
Figure 38. Regressions of leaf:stem ratios on harvest for three daylength treatments of timothy. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE=Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0001
Table 25. Temperature effects on growth of timothy plant-parts

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Total weight</th>
<th>Root weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S:R&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>21.6</td>
<td>10.4</td>
<td>48</td>
<td>5.3</td>
<td>25</td>
<td>5.9</td>
</tr>
<tr>
<td>20</td>
<td>20.7</td>
<td>9.0</td>
<td>43</td>
<td>5.0</td>
<td>24</td>
<td>6.7</td>
</tr>
<tr>
<td>Mean</td>
<td>21.2</td>
<td>9.7</td>
<td>46</td>
<td>5.2</td>
<td>25</td>
<td>6.3</td>
</tr>
<tr>
<td>SE&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.3</td>
<td>1.0</td>
<td>0.3</td>
<td>0.4</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.9160</td>
<td>0.3985</td>
<td>0.6347</td>
<td>0.0817</td>
<td>0.0012</td>
<td>0.5914</td>
</tr>
</tbody>
</table>

<sup>a</sup> Root % is calculated as root weight divided by total weight.

<sup>b</sup> Leaf:Stem ratio on a weight basis.

<sup>c</sup> Shoot:Root ratio on a weight basis.

<sup>d</sup> Standard error of a temperature mean (5 df).

<sup>e</sup> Probability of a larger F-value for the temperature effects.
Total weight, shoot weight, leaf weight, and shoot:root ratio were 6, 21, 11, and 21% higher for Timfor than for Kämpe II. Root weight and leaf:stem ratio were 5 and 9% higher for Kämpe II than for Timfor, however (Table 26). All effects, except the shoot:root ratio, were caused by Timfor being more mature (P<0.05; data not shown). Thus, Timfor has a greater ability to produce shoots relative to roots than Kämpe II, suggesting that Kämpe II produces more root material to sustain the harsher winters in its natural area of adaptation.
<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Total weight</th>
<th>Root weight&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Shoot weight</th>
<th>Leaf weight</th>
<th>L:S&lt;sup&gt;b&lt;/sup&gt;</th>
<th>S:R&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>%</td>
<td>g kg&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Timfor</td>
<td>21.8</td>
<td>9.5</td>
<td>44</td>
<td>5.7</td>
<td>26</td>
<td>6.6</td>
</tr>
<tr>
<td>Kämpe II</td>
<td>20.4</td>
<td>10.0</td>
<td>49</td>
<td>4.5</td>
<td>22</td>
<td>5.9</td>
</tr>
<tr>
<td>Mean</td>
<td>21.1</td>
<td>9.8</td>
<td>47</td>
<td>5.1</td>
<td>24</td>
<td>6.3</td>
</tr>
<tr>
<td>SE&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.0</td>
<td>0.6</td>
<td>0.3</td>
<td>0.2</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.1178</td>
<td>0.5210</td>
<td>0.0001</td>
<td>0.0005</td>
<td>0.0097</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup>Root % is calculated as root weight divided by total weight.
<sup>b</sup>Leaf:Stem ratio on a weight basis.
<sup>c</sup>Shoot:Root ratio on a weight basis.
<sup>d</sup>Standard error of a temperature mean (429 df).
<sup>e</sup>Probability of a larger F-value for the cultivar effects.
Quality characteristics

Total N and IVDMD concentrations were studied with respect to daylength, temperature, cultivars and harvests and their interactions.

Daylength and daylength interactions
Concentrations for IVDMD increased 1% as daylengths increased from 10-h to 20-h (Table 27). The IVDMD concentrations increased linearly over time at 10- and 15-h daylengths, but decreased linearly at the 20-h daylength (Fig. 39). The IVDMD concentrations increased at a higher rate over time at 10 h than at 15 h. This was both a result of lower maturity stages and higher leaf:stem ratios at 10-h. Plants grown at the 20-h daylength decreased in IVDMD concentration throughout the study because they were more mature and more stems were produced than at the other daylength treatments. Stem material is known to be less digestible than leaf material. At the first harvest, digestibilities were higher with increased daylengths. This was likely a result of the initially higher leaf:stem ratios at the higher daylengths. With advancement of time, however, shoot weight increased relatively more than leaf weight.

Total N concentrations decreased 16% as daylengths increased from 10 h to 20 h, indicating that N concentrations were diluted as growth rates increased at the longer daylengths (Table 27).

Temperature and temperature interactions
Total N concentrations remained relatively constant, whereas IVDMD concentrations decreased 8% as the temperature increased 10 °C (Table 28). Thus, daylength had a much larger effect on total N, whereas temperature had a much larger effect on IVDMD concentrations (Tables 27 and 28). Deinum and Dirven (1975) suggested that increased temperatures favor structural carbohydrates over nonstructural carbohydrates, which may explain why IVDMD concentrations decreased.

The IVDMD concentrations changed curvilinearly over time and at different rates at 10 °C and 20 °C (Fig. 40). Time of harvest only had a marginal effect on
Table 27. Daylength effects on forage quality characteristics averaged over two timothy cultivars

<table>
<thead>
<tr>
<th>Daylength</th>
<th>IVDMD$^a$</th>
<th>N$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>h</td>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>10</td>
<td>658</td>
<td>38</td>
</tr>
<tr>
<td>15</td>
<td>671</td>
<td>35</td>
</tr>
<tr>
<td>20</td>
<td>666</td>
<td>32</td>
</tr>
<tr>
<td>Mean</td>
<td>665</td>
<td>35</td>
</tr>
<tr>
<td>SE$^c$</td>
<td>13.6</td>
<td>2.0</td>
</tr>
<tr>
<td>P&gt;F$^d$</td>
<td>0.6711</td>
<td>0.0671</td>
</tr>
</tbody>
</table>

$^a$In vitro dry matter digestibility.
$^b$Total Kjeldahl nitrogen.
$^c$Standard error of a daylength mean (5 df).
$^d$Probability of a larger F-value for daylength effects.
Figure 39. Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for three daylength treatments of timothy. Data from each daylength were regressed on a mean value from replications, experiments, temperatures, and cultivars. SE = Square root of mean square lack of fit from daylength by harvest interaction. The daylength by harvest interaction was significant at P=0.0035.
Table 28. Temperature effects on forage quality characteristics averaged over two timothy cultivars

<table>
<thead>
<tr>
<th>Temperature</th>
<th>IVDMD$^a$</th>
<th>N$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>g kg$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>693</td>
<td>35</td>
</tr>
<tr>
<td>20</td>
<td>637</td>
<td>36</td>
</tr>
<tr>
<td>Mean</td>
<td>665</td>
<td>36</td>
</tr>
<tr>
<td>SE$a^c$</td>
<td>11.1</td>
<td>1.6</td>
</tr>
<tr>
<td>P&gt;F$^d$</td>
<td>0.0037</td>
<td>0.6217</td>
</tr>
</tbody>
</table>

$^a$ In vitro dry matter digestibility.
$^b$ Total Kjeldahl nitrogen.
$^c$ Standard error of a temperature mean (5 df).
$^d$ Probability of a larger F-value for temperature effects.
Figure 40. Regressions of *in vitro* dry matter digestibility (IVDMD) concentrations on harvest for two temperature treatments of timothy. Data from each temperature were regressed on a mean value from replications, experiments, daylengths, and cultivars. SE=Square root of mean square lack of fit from temperature by harvest interaction. The temperature by harvest interaction was significant at P=0.0002.
the change of IVDMD concentrations at 20 °C. Although plants advanced in maturity over time, new tillers continuously were produced to offset decreases in IVDMD concentrations. Plants grown at 10 °C had higher IVDMD concentrations than those grown at 20 °C throughout the study. Plants grown at 10 °C increased in IVDMD concentrations up to harvest 5, likely because advancement of maturity lagged and because new tillers were continuously formed. The IVDMD concentrations then decreased at approximately the same time as stage of maturity increased at a higher rate.

Cultivar Kämpe II had 6% higher N concentrations and 2% higher IVDMD concentrations than Timfor (Table 29). Maturity effects alone do not explain these differences because analysis of covariance by using stage of maturity as a covariable indicated that cultivars were still different (P<0.05; data not shown). Cultivars were likely different because Kämpe II had higher leaf:stem ratios and lower shoot:root ratios than Timfor. Leaves are known to be more digestible than stems and to have higher N concentrations (Brignall et al., 1989). Because Kämpe II had a larger root system than Timfor, it is possible that relatively more structural carbohydrates were deposited to roots than to above-ground herbage resulting in higher digestibilities of above-ground herbage. A larger root system also may enhance N uptake (Rognli, 1988) and thus cause higher herbage N-concentrations.
Table 29. Cultivar effects on forage quality characteristics averaged over two timothy cultivars, Timfor and Kämpe II

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>IVDMD&lt;sup&gt;a&lt;/sup&gt;</th>
<th>N&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timfor</td>
<td>660</td>
<td>34</td>
</tr>
<tr>
<td>Kämpe II</td>
<td>670</td>
<td>36</td>
</tr>
<tr>
<td>Mean</td>
<td>665</td>
<td>35</td>
</tr>
<tr>
<td>SE&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0022</td>
<td>0.0027</td>
</tr>
</tbody>
</table>

<sup>a</sup>In vitro dry matter digestibility.
<sup>b</sup>Total Kjeldahl nitrogen.
<sup>c</sup>Standard error of a cultivar mean (5 df).
<sup>d</sup>Probability of a larger F-value for cultivar effects.
'Apollo' and 'Vertus' alfalfa were grown at Ames IA, Arlington WI, Rosemount MN, and Grand Rapids MN. Because of difficulty in establishment and winter kill, alfalfa was absent from Grand Rapids in 1984. Alfalfa was present at all locations in 1985, however. Results for maturity, IVDMD, NDF, ADF, ADL, and N will be discussed in relation to locations, harvests, and cultivars.

**Location effects**

Mean values of MSW, IVDMD, NDF, and ADF for alfalfa differed among locations in 1984 and 1985. The effect on ADL and N concentrations were significant only in 1985 (Tables 30 and 31).

Mean stage by weight values were higher at Ames and Rosemount than at other locations in both years. In 1985, mean stage values at Grand Rapids were slightly lower than those at Arlington. Alfalfa at locations with high temperature sums (Tables 5, 6, 7, and 8) was more mature, had higher NDF, ADF, and ADL concentrations and lower IVDMD concentrations. Nitrogen concentrations did not differ. Location differences were caused by differences in stage of maturity (P>0.05 when location effect adjusted for stage of maturity; data not shown).

The changes over time of MSW, IVDMD, and N differed among locations in both years (significant harvest effects; P<0.0001). In 1985, there also were different changes over time among locations for NDF, ADF, and ADL (significant location by harvest interactions). Mean stage values (Fig. 41) increased curvilinearly over time in both years, although average MSW values were similar in both years. Location differences were more obvious in 1985 than in 1984. In 1984, MSW of alfalfa increased at higher rates at Ames and Rosemount than at Arlington. The higher increasing rates at Ames and Rosemount likely were caused by higher accumulated temperature sums than those at Arlington. In 1985, alfalfa
Table 30. Stage of maturity and concentrations of various quality factors for alfalfa grown at three locations in 1984

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW a</th>
<th>IVDMD b</th>
<th>NDF c</th>
<th>ADF d</th>
<th>ADL e</th>
<th>N f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>3.1</td>
<td>669</td>
<td>404</td>
<td>334</td>
<td>59</td>
<td>33</td>
</tr>
<tr>
<td>Rosemount, MN</td>
<td>3.1</td>
<td>650</td>
<td>432</td>
<td>356</td>
<td>55</td>
<td>32</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>2.8</td>
<td>693</td>
<td>383</td>
<td>327</td>
<td>52</td>
<td>32</td>
</tr>
<tr>
<td>Mean</td>
<td>3.0</td>
<td>671</td>
<td>406</td>
<td>339</td>
<td>55</td>
<td>32</td>
</tr>
<tr>
<td>SE g</td>
<td>0.03</td>
<td>3.0</td>
<td>4.5</td>
<td>2.9</td>
<td>3.2</td>
<td>0.4</td>
</tr>
<tr>
<td>P&gt;F h</td>
<td>0.0087</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.3453</td>
<td>0.1907</td>
</tr>
</tbody>
</table>

aMean stage by weight according to Kalu and Fick (1981).
b*In vitro* dry matter digestibility.
cNeutral detergent fiber.
dAcid detergent fiber.
eAcid detergent lignin.
fTotal Kjeldahl N.
gStandard error of a location mean. The MSW mean is based on 32 observations. All other means are based on 64 observations.
hProbability of a larger F-value.
Table 31. Stage of maturity and concentrations of various quality factors for alfalfa grown at four locations in 1985

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IVDMD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>NDF&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ADF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ADL&lt;sup&gt;e&lt;/sup&gt;</th>
<th>N&lt;sup&gt;f&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>3.5</td>
<td>649</td>
<td>436</td>
<td>332</td>
<td>66</td>
<td>32</td>
</tr>
<tr>
<td>Rosemount, MN</td>
<td>3.6</td>
<td>650</td>
<td>402</td>
<td>330</td>
<td>62</td>
<td>35</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>2.5</td>
<td>693</td>
<td>376</td>
<td>268</td>
<td>49</td>
<td>29</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>2.9</td>
<td>648</td>
<td>434</td>
<td>337</td>
<td>64</td>
<td>29</td>
</tr>
<tr>
<td>Mean</td>
<td>3.1</td>
<td>660</td>
<td>412</td>
<td>317</td>
<td>60</td>
<td>31</td>
</tr>
<tr>
<td>SE&lt;sup&gt;g&lt;/sup&gt;</td>
<td>0.09</td>
<td>4.8</td>
<td>6.2</td>
<td>4.0</td>
<td>1.4</td>
<td>0.7</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;h&lt;/sup&gt;</td>
<td>0.0036</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage by weight according to Kalu and Fick (1981).
<sup>b</sup>In vitro dry matter digestibility.
<sup>c</sup>Neutral detergent fiber.
<sup>d</sup>Acid detergent fiber.
<sup>e</sup>Acid detergent lignin.
<sup>f</sup>Total Kjeldahl N.
<sup>g</sup>Standard error of a location mean. The MSW mean is based on 32 observations. All other means are based on 64 observations.
<sup>h</sup>Probability of a larger F-value.
Figure 41. Regressions of mean stage by weight values on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and two replications. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
at Rosemount increased the most between harvests 1 and 5, whereas at Grand Rapids the increases were more pronounced between harvests 5 and 8. At Rosemount, there were high temperature sums and relatively high rainfall during the period of rapid increase in maturity (Table 7). Maturity of alfalfa at Grand Rapids progressed at high rates when rainfall was high and temperature sums were moderate (Table 8).

The IVDMD concentrations of alfalfa decreased linearly over time in 1984, and curvilinearly over time in 1985 (Fig. 42). The range in IVDMD concentrations over time was larger in 1984 than in 1985, whereas differences between locations were larger in 1985 than in 1984. Furthermore, the decline in IVDMD concentrations tended to follow increases in stage of maturity in 1984, but not in 1985. In 1984, IVDMD concentrations were higher and decreased more rapidly at Arlington and Rosemount than at Ames. The slower decline at Ames was not expected because maturity advanced at higher rates than at the other locations. In 1985, IVDMD concentrations increased from first to third harvest and decreased thereafter at all locations, although the decline was smaller at Grand Rapids.

Higher than optimum growth temperatures are known to increase leaf:stem ratios (Faix, 1974), resulting in higher digestibilities because leaves are more digestible than stems. Apparently IVDMD concentrations and MSW simultaneously increased between harvests 1 and 3 as a result of high temperatures that both caused increased maturity stages and increased leaf:stem ratios (Tables 5, 6, 7, and 8).

Nitrogen concentrations decreased curvilinearly over time in 1984 and linearly in 1985 (Fig. 43). The differences among locations were larger in 1985 than in 1984. Nitrogen concentrations also tended to be lower and decrease over time at lower rates in 1985 than in 1984. In 1984, nitrogen concentrations were highest and decreased at the highest rate over time at Rosemount, followed by Ames and Arlington in both years. In 1985, N concentrations at Grand Rapids were initially lower and changed the least over time compared with the other
Figure 42. Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and four replications. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0369 in 1984 and P=0.0001 in 1985.
Figure 43. Regressions of total nitrogen (N) concentrations on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and four replications. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0027 in 1984 and P=0.0001 in 1985.
locations. Because no yield data were recorded, it can only be assumed that N concentrations were diluted as a result of differential growth rates of alfalfa among locations. Maturity data indicate, however, that growth rates were highest at Rosemount and lowest at Grand Rapids.

Concentrations of NDF, ADF, and ADL increased curvilinearly over time and showed similar trends within locations in both years (Figs. 44, 45, and 46). The location by harvest interactions only were significant in 1985, however. Changes in NDF, ADF, and ADL concentrations tended to follow changes in stage of maturity. In 1984, increases in NDF, ADF, and ADL concentrations also tended to be the opposite of changes in IVDMD concentrations over time. These results are consistent with earlier reports stating that reduced digestibility is a result of higher concentrations of hemicellulose, cellulose, and lignin. In 1985, NDF, ADF, and ADL concentrations increased the most over time at Rosemount and the least at Grand Rapids. At Ames and Arlington, NDF, ADF, and ADL concentrations over time were characterized by first increasing followed by a plateau. It is more difficult to explain why NDF, ADF, and ADL did not follow changes in IVDMD concentrations in 1985. It is possible that fiber becomes less digestible with progression of time under hot and dry conditions.

Cultivar effects

The American and Swedish cultivars of alfalfa had similar IVDMD, NDF, ADF, ADL, and N concentrations in both years (Tables 32 and 33). Stage of maturity was inconsistently different for the two cultivars in 1984 and 1985. There were no differences in MSW among cultivars in 1984 (Fig. 47). In 1985, however, the American cultivar was more mature at Ames and Grand Rapids, but there were no differences at Rosemount and Arlington. Because cultivar effects were inconsistent between years, any interpretation of the cultivar by location interaction in 1985 is difficult.
Figure 44. Regressions of neutral detergent fiber (NDF) concentrations on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and four replications. Equations are listed in the same order as locations in legends. SE = Square root of the residual mean square. The location by harvest interaction was significant at $P = 0.0873$ in 1984 and $P = 0.0001$ in 1985.
Figure 45. Regressions of acid detergent fiber (ADF) concentrations on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and four replications. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at \( P=0.0844 \) in 1984 and \( P=0.0001 \) in 1985.
Figure 46. Regressions of acid detergent lignin (ADL) concentrations on harvest for alfalfa in 1984 and 1985. Data from each location and year were regressed on two cultivars and four replications. Equations are listed in the same order as locations in legends. $SE=\text{Square root of the residual mean square.}$ The location by harvest interaction was significant at $P=0.3777$ in 1984 and $P=0.0001$ in 1985.
### Table 32. Effects of alfalfa cultivars on MSW and concentrations of various quality factors in 1984 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW $^a$</th>
<th>IVDMD $^b$</th>
<th>NDF $^c$</th>
<th>ADF $^d$</th>
<th>ADL $^e$</th>
<th>N $^f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo II</td>
<td>2.9</td>
<td>668</td>
<td>406</td>
<td>343</td>
<td>53</td>
<td>33</td>
</tr>
<tr>
<td>Vertus</td>
<td>3.0</td>
<td>674</td>
<td>406</td>
<td>336</td>
<td>58</td>
<td>32</td>
</tr>
<tr>
<td>Mean</td>
<td>3.0</td>
<td>671</td>
<td>406</td>
<td>340</td>
<td>56</td>
<td>32</td>
</tr>
<tr>
<td>SE $^g$</td>
<td>0.02</td>
<td>4.3</td>
<td>5.0</td>
<td>6.0</td>
<td>2.2</td>
<td>0.5</td>
</tr>
<tr>
<td>P&gt;F $^h$</td>
<td>0.0227</td>
<td>0.3035</td>
<td>0.9192</td>
<td>0.3984</td>
<td>0.1898</td>
<td>0.7818</td>
</tr>
</tbody>
</table>

$^a$Mean stage by weight according to Kalu and Fick (1981).
$^b$In vitro dry matter digestibility.
$^c$Neutral detergent fiber.
$^d$Acid detergent fiber.
$^e$Acid detergent lignin.
$^f$Total Kjeldahl N.
$^g$Standard error of a cultivar mean. The MSW mean is based on 48 observations. All other means are based on 96 observations.
$^h$Probability of a larger F-value.
Table 33. Effects of alfalfa cultivars on MSW and concentrations of various quality factors in 1985 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSWa</th>
<th>IVDMDb</th>
<th>NDFc</th>
<th>ADFd</th>
<th>ADLe</th>
<th>Nf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apollo II</td>
<td>3.2</td>
<td>660</td>
<td>413</td>
<td>315</td>
<td>61</td>
<td>32</td>
</tr>
<tr>
<td>Vertus</td>
<td>3.0</td>
<td>656</td>
<td>415</td>
<td>319</td>
<td>61</td>
<td>31</td>
</tr>
<tr>
<td>Cultivar mean</td>
<td>3.1</td>
<td>658</td>
<td>414</td>
<td>317</td>
<td>61</td>
<td>32</td>
</tr>
<tr>
<td>SEg</td>
<td>0.02</td>
<td>3.3</td>
<td>2.6</td>
<td>2.4</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>P&gt;Fh</td>
<td>0.0013</td>
<td>0.4714</td>
<td>0.6110</td>
<td>0.3419</td>
<td>0.8809</td>
<td>0.2472</td>
</tr>
</tbody>
</table>

* Mean stage by weight according to Kalu and Fick (1981).
* In vitro dry matter digestibility.
* Neutral detergent fiber.
* Acid detergent fiber.
* Acid detergent lignin.
* Total Kjeldahl N.
* Standard error of a cultivar mean. The MSW mean is based on 64 observations. All other means are based on 128 observations.
* Probability of a larger F-value.
Figure 47. Mean stage by weight values at four locations in 1984 and 1985 as affected by two alfalfa cultivars. Each cultivar mean is based on eight harvests and two replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Maturity of Apollo II advanced at higher rates over time than that of Vertus (significant cultivar by harvest interaction in 1985) (Fig. 48). The interaction does not appear to be biologically significant, however.
Figure 48. Regressions of mean stage by weight on harvest for two alfalfa cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and 4 replications at each harvest in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at \( P=0.6689 \) in 1984 and \( P=0.0001 \) in 1985. SE=Square root of the residual mean square; SE=NS when \( P>0.05 \).
Red Clover - Field Study

'Arlington' and 'Hermes II' red clover were grown at Ames IA, Arlington WI, Rosemount MN, and Grand Rapids MN. Because of difficulty in establishment and winter kill, Arlington and Hermes II were absent from Grand Rapids and Hermes II was absent from Rosemount in 1984. Red clover was present at all locations in 1985, however. Results of maturity, IVDMD, NDF, ADF, ADL, and N will be discussed in relation to locations, harvests, and cultivars.

**Location effects**

Mean values of MSW, IVDMD, NDF, ADF, ADL, and N for red clover differed among locations in both years; values were inconsistent between years, however (Tables 34 and 35). In 1984, MSW values of red clover were highest at Rosemount likely because the Swedish cultivar was absent. Northern cultivars are known to initiate growth later and have lower maturity values than southern cultivars when grown south of their origin, and harvested at the same time. Arlington red clover at Rosemount also had the lowest IVDMD and N concentrations, and the highest NDF, ADF, and ADL concentrations. These results are consistent with previous reports stating that advancement in maturity reduces digestibility, increases fiber concentrations, and generally reduces N concentrations. In 1985, average MSW values, and ADF and ADL concentrations were highest, whereas N concentrations were lowest at Grand Rapids. The IVDMD concentrations were lowest and the NDF concentrations were highest at Ames, even though plants were more mature at Grand Rapids than at Ames. It is likely that hot and dry weather at Ames resulted in high fiber concentrations even at relatively low maturity stages.

Mean stage by weight increased curvilinearly over time in both years, but trends differed between locations (Fig. 49). In 1984, red clover matured more rapidly at Rosemount than at Ames and Arlington probably because means from
Table 34. Stage of maturity and concentrations of various quality factors for red clover grown at three locations in 1984

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IVDMD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>NDF&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ADF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ADL&lt;sup&gt;e&lt;/sup&gt;</th>
<th>N&lt;sup&gt;f&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>1.6</td>
<td>709</td>
<td>355</td>
<td>279</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>Rosemount, MN&lt;sup&gt;g&lt;/sup&gt;</td>
<td>2.9</td>
<td>693</td>
<td>392</td>
<td>313</td>
<td>47</td>
<td>28</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>2.0</td>
<td>733</td>
<td>334</td>
<td>271</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>Mean</td>
<td>2.2</td>
<td>712</td>
<td>360</td>
<td>288</td>
<td>43</td>
<td>31</td>
</tr>
<tr>
<td>SE&lt;sup&gt;h&lt;/sup&gt;</td>
<td>0.03</td>
<td>5.4</td>
<td>4.2</td>
<td>6.0</td>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;i&lt;/sup&gt;</td>
<td>0.0006</td>
<td>0.0033</td>
<td>0.0001</td>
<td>0.0047</td>
<td>0.0173</td>
<td>0.0032</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage by weight according to Kalu and Fick (1981).
<sup>b</sup>In vitro dry matter digestibility.
<sup>c</sup>Neutral detergent fiber.
<sup>d</sup>Acid detergent fiber.
<sup>e</sup>Acid detergent lignin.
<sup>f</sup>Total Kjeldahl N.
<sup>g</sup>Location mean is only for one red clover cultivar (Arlington).
<sup>h</sup>Standard error of a location mean. The MSW mean is based on 26 observations. All other means are based on 53 observations.
<sup>i</sup>Probability of a larger F-value.
Table 35. Stage of maturity and concentrations of various quality factors for red clover grown at four locations in 1985

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW $^a$</th>
<th>IVDMD $^b$</th>
<th>NDF $^c$</th>
<th>ADF $^d$</th>
<th>ADL $^e$</th>
<th>N $^f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>1.6</td>
<td>718</td>
<td>355</td>
<td>232</td>
<td>31</td>
<td>34</td>
</tr>
<tr>
<td>Rosemount, MN</td>
<td>1.8</td>
<td>743</td>
<td>319</td>
<td>235</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>1.9</td>
<td>726</td>
<td>341</td>
<td>261</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>1.5</td>
<td>738</td>
<td>337</td>
<td>243</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Mean</td>
<td>1.7</td>
<td>731</td>
<td>338</td>
<td>243</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>SE $^g$</td>
<td>0.05</td>
<td>6.4</td>
<td>3.1</td>
<td>5.2</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>P&gt;F $^h$</td>
<td>0.0142</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0156</td>
<td>0.0160</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

$^a$Mean stage by weight according to Kalu and Fick (1981).
$^b$In vitro dry matter digestibility.
$^c$Neutral detergent fiber.
$^d$Acid detergent fiber.
$^e$Acid detergent lignin.
$^f$Total Kjeldahl N.
$^g$Standard error of a location mean. The MSW mean is based on 32 observations. All other means are based on 64 observations.
$^h$Probability of a larger F-value.
Figure 49. Regressions of mean stage by weight values on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and two replications at each harvest. Data from Rosemount were regressed on one cultivar and two replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and two replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
Rosemount only included Arlington red clover. Red clover matured faster at Ames than at Arlington likely as a result of more rain and higher temperatures at Ames (Tables 5 and 6). In 1985, red clover tended to mature at higher rates at Arlington and Rosemount than at Ames and Grand Rapids, but average maturity was highest among locations at Grand Rapids. The slower rate of maturity increase over time at Ames and Grand Rapids may be related to high temperatures and low rainfall at Ames and low temperatures and high rainfall at Grand Rapids. These results were not consistent with results of maturity changes of red clover in the growth chamber experiment (section Red Clover - Growth Chamber) in which increased temperature caused an increase in maturity. However, the effect of drought in combination with different temperatures was not studied.

The IVDMD concentrations changed curvilinearly over time in both years (Fig. 50). Digestibilities decreased at slower rates in 1985 than in 1984. In 1984, IVDMD concentrations initially increased or remained stable before decreasing. Concentrations decreased at the slowest rate at Ames followed by Rosemount and Arlington locations. Even though red clover at Rosemount was more mature, the IVDMD concentration was not noticeably lower at Rosemount than at Ames or Arlington, indicating that decline in digestibility does not always follow increases in maturity. Unlike results in 1984, however, IVDMD concentrations in 1985 decreased more rapidly at Ames and Rosemount than at Arlington and Grand Rapids. This may be a result of higher temperatures at Ames and Rosemount. Results from the growth chamber experiments (section Red Clover - Growth Chamber) showed that increased temperature resulted in lower digestibility, but the rate of change in digestibility was similar between temperatures over time. A continuous production of new tillers of red clover may be responsible for the similar rates, however.

Nitrogen concentrations decreased curvilinearly over time in both years (Fig. 51). Average N concentrations were slightly higher in 1985 than in 1984. In 1984,
Figure 50. Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and four replications at each harvest. Data from Rosemount were regressed on one cultivar and four replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and four replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
Figure 51. Regressions of total nitrogen (N) concentrations on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and four replications at each harvest. Data from Rosemount were regressed on one cultivar and four replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and four replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0051 in 1984 and P=0.0001 in 1985.
N concentrations decreased more rapidly at Arlington and Rosemount than at Ames. This is consistent with changes in maturity at Ames and Rosemount, but not at Arlington. In 1985, N concentrations were highest and decreased at the highest rate at Rosemount followed by Ames, Arlington, and Grand Rapids locations.

Mean values of NDF, ADF, and ADL in 1984 and 1985 differed among locations (Figs. 52, 53, and 54). In 1984, NDF and ADF concentrations changed similarly within locations (Figs. 52 and 53). The NDF and ADF concentrations increased the most at Arlington and the least at Ames. The interpretation of these results is difficult because differences in rates of change were not caused by differences in stage of maturity (P > 0.05 when adjusting for stage of maturity; data not shown). The result that red clover had lower NDF and ADF concentrations and a slower rate of change at Ames than at Arlington and Rosemount was unexpected considering that Ames accumulated more growing degree days and had more rain compared with the other locations in 1984 (Tables 5, 6, and 7). The NDF and ADF concentrations were lower in 1985 than in 1984, which likely is a result of drier weather and stunted growth. The NDF and ADF concentrations tended to increase at the highest rates at Rosemount between harvests 1 and 6, although changes in ADF concentration over time was similar at Arlington, Grand Rapids, and Rosemount between harvests 2 and 5. The plateau in NDF and ADF concentrations at the beginning and end of the sampling period at Arlington and Grand Rapids is possibly linked to the lower temperature sums compared with Ames and Rosemount. Similarly, the rate of change of NDF and ADF concentrations tended to be higher at Rosemount than at the other locations because of high temperature sums. The NDF and ADF concentrations increased at a slower rate at Ames than at Rosemount possibly as a result of severe drought, although this does not explain why NDF and ADF concentrations were higher at Ames than at Rosemount for a majority of the sampling period. Hemicellulose
Figure 52. Regressions of neutral detergent fiber (NDF) concentrations on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and four replications at each harvest. Data from Rosemount were regressed on one cultivar and four replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and four replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
Figure 53. Regressions of acid detergent fiber (ADF) concentrations on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and four replications at each harvest. Data from Rosemount were regressed on one cultivar and four replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and four replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
Figure 54. Regressions of acid detergent lignin (ADL) concentrations on harvest for red clover in 1984 and 1985. Data from Ames and Arlington in 1984 were regressed on two cultivars and four replications at each harvest. Data from Rosemount were regressed on one cultivar and four replications at each harvest in 1984. Data from each location in 1985 were regressed on two cultivars and four replications at each harvest. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
Concentrations tended to be higher at Ames than at the other locations.

Concentrations of ADL changed curvilinearly over time in 1984 and 1985 (Fig. 54). In 1984, ADL concentrations changed in a nearly linear fashion at Arlington and Rosemount. Concentrations of ADL at Ames, however, initially were higher, plateaued between harvests 1 and 4, but increased thereafter. One reason for the initial plateau is that Ames received little rain in conjunction with higher temperatures two to three weeks before the first harvest, whereas precipitation was higher and temperatures lower at Arlington and Rosemount (data not shown). In both years, the ADL concentrations tended to follow changes in ADF concentrations more closely than changes in NDF concentrations at each location. Because ranges and rates of ADL concentrations differed more between years than those for NDF and ADF concentrations, it implies that ADL concentrations are more sensitive to changes in temperature and soil water.

Cultivar effects

Arlington red clover had higher concentrations of NDF, ADF, and ADL than Hermes II red clover in both years (Tables 36 and 37). Hermes II was more digestible and had higher N concentrations in both years. These differences between cultivars were caused by differences in maturity (P>0.05 when adjusting for stage of maturity; data not shown). These results are consistent with results from the growth chamber experiment (section Red Clover - Growth Chamber) in which Hermes II required longer days than the Arlington cultivar to reach reproductive development. Thus, Arlington red clover had higher fiber deposition and lower digestibility and N concentration as a result higher maturity.

Mean stage by weight differed between cultivars (significant location by cultivar interaction) in 1985 only (Fig. 55). Apparently, Hermes II was more sensitive to dry and hot weather than Arlington red clover, resulting in the lowest maturity values at Ames. Arlington seemed to respond to a combination of
Table 36. Effects of red clover cultivars on MSW and concentrations of various quality factors in 1984 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW(^a)</th>
<th>IVDMD(^b)</th>
<th>NDF(^c)</th>
<th>ADF(^d)</th>
<th>ADL(^e)</th>
<th>N(^f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlington</td>
<td>2.4</td>
<td>708</td>
<td>362</td>
<td>293</td>
<td>44</td>
<td>31</td>
</tr>
<tr>
<td>Hermes II</td>
<td>1.5</td>
<td>728</td>
<td>340</td>
<td>266</td>
<td>39</td>
<td>33</td>
</tr>
<tr>
<td>Mean</td>
<td>2.0</td>
<td>718</td>
<td>351</td>
<td>280</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>SE(^g)</td>
<td>0.03</td>
<td>2.0</td>
<td>1.9</td>
<td>2.6</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>P&gt;F(^h)</td>
<td>0.0081</td>
<td>0.0093</td>
<td>0.1022</td>
<td>0.0099</td>
<td>0.0069</td>
<td>0.0806</td>
</tr>
</tbody>
</table>

\(^a\) Mean stage by weight according to Kalu and Fick (1981).
\(^b\) In vitro dry matter digestibility.
\(^c\) Neutral detergent fiber.
\(^d\) Acid detergent fiber.
\(^e\) Acid detergent lignin.
\(^f\) Total Kjeldahl N.
\(^g\) Standard error of a cultivar mean. The MSW mean is based on 26 observations.
\(^h\) All other means are based on 53 observations.
\(^i\) Probability of a larger F-value.
Table 37. Effects of red clover cultivars on MSW and concentrations of various quality factors in 1985 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IVDMD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>NDF&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ADF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ADL&lt;sup&gt;e&lt;/sup&gt;</th>
<th>N&lt;sup&gt;f&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arlington</td>
<td>2.1</td>
<td>727</td>
<td>343</td>
<td>248</td>
<td>33</td>
<td>32</td>
</tr>
<tr>
<td>Hermes II</td>
<td>1.3</td>
<td>737</td>
<td>333</td>
<td>235</td>
<td>32</td>
<td>34</td>
</tr>
<tr>
<td>Mean</td>
<td>1.7</td>
<td>732</td>
<td>338</td>
<td>242</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>SE&lt;sup&gt;g&lt;/sup&gt;</td>
<td>0.03</td>
<td>1.5</td>
<td>1.7</td>
<td>2.0</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;h&lt;/sup&gt;</td>
<td>0.0001</td>
<td>0.0010</td>
<td>0.0015</td>
<td>0.0008</td>
<td>0.1128</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage by weight according to Kalu and Fick (1981).
<sup>b</sup>In vitro dry matter digestibility.
<sup>c</sup>Neutral detergent fiber.
<sup>d</sup>Acid detergent fiber.
<sup>e</sup>Acid detergent lignin.
<sup>f</sup>Total Kjeldahl N.
<sup>g</sup>Standard error of a cultivar mean. The MSW mean is based on 64 observations.
<sup>h</sup>Probability of a larger F-value.

All other means are based on 128 observations.
Figure 55. Mean stage by weight values at three locations in 1984 and four locations 1985 as affected by two red clover cultivars. (Hermes II was missing from Rosemount in 1984). Each cultivar mean is based on eight harvests and two replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
temperatures and soil water such that high temperatures could offset low rainfall, resulting in higher maturity stages at Ames than at Arlington.

Mean N concentrations differed between cultivars (significant location by cultivar interaction) in both years (Fig. 56). In 1984, the Hermes II cultivar had higher N concentration than Arlington only at Ames. In 1985, Hermes II had higher N concentrations than Arlington at all four locations; however, differences in N concentrations between the two cultivars were largest at Arlington and Ames. These locations received the lowest rainfall. The higher N concentration of Hermes II is likely a result of lesser growth of Hermes II. However, Hermes II could have more efficient N uptake because of its larger root system compared with Arlington (confirmed in growth chamber experiment).

Mean values of IVDMD concentrations for the two cultivars differed only at Ames (significant cultivar interaction) in 1984 (Fig. 57). This interaction was caused by maturity differences between cultivars (P > 0.05 when adjusting for stage of maturity; data not shown).

There was a significant location by cultivar interaction for both NDF and ADF in 1984 (Figs. 58 and 59). Cultivars were different at Ames, but not at Arlington. In 1985, Hermes II tended to have lower NDF and ADF concentrations than the Arlington cultivar. Because of these inconsistencies between years, any interpretation is difficult to make.

There were significant cultivar by harvest interactions for MSW and IVDMD in 1984. In 1985, this interaction was significant for MSW, IVDMD, NDF, ADF, and ADL. In 1985, there also were significant harvest by cultivar interactions for ADF and ADL concentrations; however neither linear, quadratic, nor cubic relationships over time were significant. Therefore, no data from these variables will be presented.

The cultivar Arlington matured more rapidly over time than Hermes II (Fig. 60). These results also were confirmed in the growth chamber study (section Red
Figure 56. Total nitrogen (N) concentrations at three locations in 1984 and four locations 1985 as affected by two red clover cultivars. (Hermes II was missing from Rosemount in 1984). Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square.
Figure 57. *In vitro* dry matter digestibility (IVDMD) concentrations at three locations in 1984 and four locations in 1985 as affected by two red clover cultivars. (Hermes II was missing from Rosemount in 1984). Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value ($P>F$) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when $P>F$ is greater than 0.05.
Figure 58. Neutral detergent fiber (NDF) concentrations at three locations in 1984 and four locations 1985 as affected by two red clover cultivars. (Hermes II was missing from Rosemount in 1984). Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 59. Acid detergent fiber (ADF) concentrations at three locations in 1984 and four locations 1985 as affected by two red clover cultivars. (Hermes II was missing from Rosemount in 1984). Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 60. Regressions of mean stage by weight on harvest for two red clover cultivars in 1984 and 1985. Data from 'Arlington' were regressed on three locations and two replications at each harvest in 1984. Data from 'Hermes II' were regressed on two locations and two replications at each harvest in 1984. Data from each cultivar were regressed on four locations and two replications at each harvest in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at $P=0.0001$ in both years. SE=Squre root of the residual mean square.
Clover -Growth Chamber). Hermes II has a longer critical photoperiod than Arlington and, therefore, is not expected to mature as rapidly under Midwestern conditions.

The IVDMD concentrations were higher for Hermes II than for Arlington red clover in both years (Fig. 61). In 1984, the IVDMD concentration decreased more rapidly for Arlington than for Hermes II. In 1985, IVDMD concentrations increased more rapidly for Arlington than for Hermes II between harvests 1 and 3, after which both cultivars decreased at comparable rates. Digestibilities decreased at higher rates over time in 1984 than in 1985.

In 1985, NDF concentrations increased more rapidly over time for Hermes II than for the Arlington cultivar (Fig. 62). In 1984, Arlington also tended to deposit less NDF than Hermes II at the initial and final two harvests, although the interaction was not significant. Although average NDF concentrations were higher for Arlington than for Hermes II, it is surprising that Hermes II tended to deposit NDF at higher rates than Arlington because Arlington matured more rapidly (Fig. 60). Thus, physiological age may be a better indicator of NDF concentrations than stage of maturity, at least when genetically diverse red clovers are compared.
Figure 61. Regressions of *in vitro* dry matter digestibility (IVDMD) concentrations on harvest for two red clover cultivars in 1984 and 1985. Data from 'Arlington' were regressed on three locations and four replications at each harvest in 1984. Data from 'Hermes II' were regressed on two locations and four replications at each harvest in 1984. Data from each cultivar were regressed on four locations and four replications at each harvest in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at $P=0.0389$ in 1984 and $P=0.0006$ in 1985. SE=Square root of the residual mean square.
Figure 62. Regressions of neutral detergent fiber (NDF) concentrations on harvest for two red clover cultivars in 1984 and 1985. Data from 'Arlington' were regressed on three locations and four replications at each harvest in 1984. Data from 'Hermes II' were regressed on two locations and four replications at each harvest in 1984. Data from each cultivar were regressed on four locations and four replications at each harvest in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at P=0.3872 in 1984 and P=0.0002 in 1985. SE=Square root of the residual mean square.
'Timfor' and 'Kämpe II' timothy were grown at Ames IA, Arlington WI, Rosemount MN, and Grand Rapids MN. Because of difficulty in establishment, timothy was absent from Rosemount in 1984. Timothy was present at all locations in 1985, however. Results of maturity, IVMD, NDF, ADF, ADL, and N concentrations will be discussed in relation to locations, harvests, and cultivars.

Location effects

Mean values of MSW, IVMD, NDF, ADF, ADL, and N for timothy differed among locations in 1984 and 1985 (Tables 38 and 39). Average MSW values were higher at Grand Rapids than at Ames and Arlington in both years. In 1985, MSW values at Rosemount and Grand Rapids were similar. The ranking in MSW among locations corresponded well with temperature sums in 1984, i.e. high temperature sums resulted in high MSW values (Tables 5, 6, and 8). In 1985, maturity was high at Grand Rapids despite low temperature sums. Grand Rapids received more rain than the other locations, however (Tables 5, 6, 7, and 8). Therefore, it is possible that the dry weather at the other locations negatively affected stage of development.

The IVMD concentrations were reverse in ranking compared with MSW values in 1984, i.e. high MSW values resulted in low IVMD concentrations. In 1985, this relationship was not as evident as in 1984. Timothy at Arlington and Rosemount had similar IVMD concentrations although plants were 4.3 units more mature at Rosemount.

The NDF, ADF, and ADL concentrations generally were higher at locations where timothy was more mature and less digestible. Timothy grown at Grand Rapids in 1985 differed from the other locations, however, by having relatively high digestibilities and low NDF, ADF, and ADL concentrations. This
Table 38. Stage of maturity and concentrations of various quality factors for timothy grown at three locations in 1984

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IVDMD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>NDF&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ADF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ADL&lt;sup&gt;e&lt;/sup&gt;</th>
<th>N&lt;sup&gt;f&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>42.3</td>
<td>655</td>
<td>586</td>
<td>334</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>48.9</td>
<td>619</td>
<td>614</td>
<td>356</td>
<td>41</td>
<td>19</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>37.2</td>
<td>684</td>
<td>553</td>
<td>304</td>
<td>32</td>
<td>24</td>
</tr>
</tbody>
</table>

Mean 42.8 653 584 331 35 21

SE<sup>g</sup> 2.18 5.2 5.0 2.6 1.0 0.4

P>F<sup>h</sup> 0.0344 0.0001 0.0001 0.0001 0.0001

<sup>a</sup>Mean stage by weight according to Simon and Park (1981).
<sup>b</sup>In vitro dry matter digestibility.
<sup>c</sup>Neutral detergent fiber.
<sup>d</sup>Acid detergent fiber.
<sup>e</sup>Acid detergent lignin.
<sup>f</sup>Total Kjeldahl N.
<sup>g</sup>Standard error of a location mean. The MSW mean is based on 30 observations.
<sup>h</sup>Probability of a larger F-value.

All other means are based on 61 observations.
Table 39. Stage of maturity and concentrations of various quality factors for timothy grown at four locations in 1985

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW$^a$</th>
<th>IVDMD$^b$</th>
<th>NDF$^c$</th>
<th>ADF$^d$</th>
<th>ADL$^e$</th>
<th>N$^f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>36.2</td>
<td>710</td>
<td>535</td>
<td>284</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td>Rosemount, MN</td>
<td>43.7</td>
<td>673</td>
<td>577</td>
<td>320</td>
<td>32</td>
<td>29</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>43.1</td>
<td>693</td>
<td>550</td>
<td>310</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>39.3</td>
<td>677</td>
<td>593</td>
<td>328</td>
<td>32</td>
<td>26</td>
</tr>
<tr>
<td>Mean</td>
<td>40.6</td>
<td>688</td>
<td>564</td>
<td>311</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>SE$^g$</td>
<td>0.40</td>
<td>4.9</td>
<td>5.0</td>
<td>3.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>P&gt;F$^h$</td>
<td>0.0005</td>
<td>0.0006</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0275</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

$^a$Mean stage by weight according to Simon and Park (1981).
$^b$In vitro dry matter digestibility.
$^c$Neutral detergent fiber.
$^d$Acid detergent fiber.
$^e$Acid detergent lignin.
$^f$Total Kjeldahl N.
$^g$Standard error of a location mean. The MSW mean is based on 32 observations. All other means are based on 64 observations.
$^h$Probability of a larger F-value.
might have been related to slightly lower temperature sums in 1985 than in 1984. Timothy at Arlington also had high fiber concentrations and low digestibilities in spite of low MSW values.

Nitrogen concentrations generally were higher at locations where timothy was less mature. This is consistent with results of Mitchell (1987) who found that timothy and bromegrass had low N concentrations during periods of rapid development.

Analysis of covariance by using MSW as a covariable revealed that location effects for IVDMD, NDF, ADF, ADL, and N concentrations were a result of maturity differences (data not shown).

There was a significant location by harvest interaction for MSW, IVDMD, N, NDF, ADF, and ADL in 1984 and 1985. Stage of maturity increased curvilinearly over time in both years (Fig. 63). Rate of change over time in maturity was similar at Arlington and Grand Rapids in both years. Development of timothy grown at Ames increased at lower rates over most harvests in 1984 than in 1985. In 1984, average maturity was higher for timothy grown at Grand Rapids than at Ames and Arlington at comparable harvests; however, stage of maturity tended to increase at the highest rate over time at Ames. Thus, growth of timothy was initiated earlier at Grand Rapids than at Ames and Arlington. This likely was a result of higher temperature sums at the initial harvests at Grand Rapids (Tables 5, 6, and 8). The earlier start of growth at Grand Rapids also resulted in a plateau at the final harvest, a pattern that was less evident at Ames and Arlington. In 1985, MSW values at most harvests increased at comparable rates at Rosemount and Grand Rapids. Stage of maturity at Ames, however, increased at the lowest rate among locations between harvests 1 and 6, after which maturity increased at the highest rate. The initially slow development over time for timothy at Ames was probably a result of severe drought. Ames only received 85 mm of rain during the study in
Figure 63. Regressions of mean stage by weight values on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and two replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE = Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
1985 (Table 5). Timothy at Arlington matured at higher rates over time than at Rosemount and Grand Rapids likely because temperature sums were lower at Arlington than at Rosemount and precipitation was lower at Arlington than at Grand Rapids (Tables 6, 7, and 8).

The IVDMD concentrations decreased curvilinearly over time in 1984 and 1985 (Fig. 64). The range in IVDMD concentrations and the rate of decline over time were larger in 1984 than in 1985. These results likely were caused by dry weather and stunted growth in 1985. Furthermore, changes in digestibility tended to follow changes in stage of maturity in both years except at Ames in 1985. In 1984, IVDMD concentrations decreased similarly over time between locations except at the final two harvests when digestibilities plateaued at Ames and Grand Rapids. This was likely because stage of maturity plateaued at Ames and Grand Rapids. In 1985, IVDMD concentrations over time decreased at the highest rates at Rosemount. There were relatively high temperatures and rainfall at Rosemount compared with the other locations (Tables 5, 6, 7, 8). The decline in digestibility at the final three harvests was unexpectedly low for timothy at Ames. Even though stage of maturity increased rapidly, the rate of digestibility decline was stable. The dry weather at Ames resulted in reduced growth and likely a high leaf:stem ratio, factors which may explain the relatively high digestibilities despite rapid development.

Nitrogen concentrations declined curvilinearly over time in 1984 and 1985 (Fig. 65). Nitrogen concentrations were higher in 1985 than in 1984 likely as a result of hotter and drier weather, which negatively affected growth. Because no yield data were recorded, it is difficult to interpret changes in N concentrations over time. In 1984, N concentrations were highest at Arlington followed by Ames and Grand Rapids. Nitrogen concentrations at both Arlington and Ames decreased rapidly between harvests 1 and 5 after which concentrations plateaued. Concentrations at Grand Rapids decreased in a
Figure 64. Regressions of in vitro dry matter digestibility (IVDMD) concentrations on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. $SE = \text{Square root of the residual mean square}$. The location by harvest interaction was significant at $P=0.0001$ in both years.
Figure 65. Regressions of total nitrogen (N) concentrations on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
nearly linear fashion throughout the harvest period. Lower temperatures and more mature timothy at Grand Rapids compared with Ames and Arlington might have contributed to the lower N concentrations. The lower decline over time for N concentrations at Grand Rapids might have been caused by lower soil N levels. The Grand Rapids soil is sandier compared with the other locations. In 1985, N concentrations at each harvest were lowest at Grand Rapids, thus following the same trends as in 1984. Unlike results in 1984, however, timothy at Ames had higher N concentrations than timothy at Arlington, which probably was a result of droughty conditions at Ames.

The NDF and ADF concentrations increased linearly over time in 1984 and curvilinearly in 1985 (Figs. 66 and 67). The NDF and ADF concentrations tended to be lower and to increase at lower rates over time in 1985 than in 1984. Changes in NDF and ADF concentrations over time tended to follow changes in stage of maturity, whereas they were opposite of changes in IVDMD concentrations. In 1984, NDF and ADF concentrations increased over time at the highest rates at Arlington and at the lowest rates at Grand Rapids. In 1985, concentrations of NDF and ADF increased the least over time at Ames probably as a result of the initially slow development and dry conditions. Furthermore, the rate of increase over time of NDF and ADF concentrations was unexpectedly low at Arlington considering rapid maturation based on MSW values (Figs. 63, 66, and 67).

The ADL concentrations increased linearly over time in 1984 and curvilinearly over time in 1985 (Fig. 68). Lignin concentrations were lower and increased at slower rates in 1985 than in 1984 likely as a result of drier and warmer weather. In 1984, ADL concentrations were highest and increased the most over time at Grand Rapids compared with the other locations. This may be a result of earlier growth of timothy at Grand Rapids. Timothy at Ames had the lowest rate of lignin deposition. This was unexpected because both
Figure 66. Regressions of neutral detergent fiber (NDF) concentrations on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
1984

Ames, IA

Grand Rapids, MN

Arlington, WI

Y = 190.506 + 31.885H
R^2 = 0.86 SE = 29.650

Y = 234.916 + 30.384H
R^2 = 0.85 SE = 25.940

Y = 148.171 + 34.616H
R^2 = 0.85 SE = 33.497

1985

Ames, IA

Y = 204.196 + 33.668H - 4.363H^2 + 0.030H^3
R^2 = 0.77 SE = 15.224

Rosemount, MN

Y = 190.562 + 42.553H - 2.575H^2 + 0.030H^3
R^2 = 0.87 SE = 19.993

Grand Rapids, MN

Y = 272.312 - 24.611H + 10.850H^2 - 0.753H^3
R^2 = 0.85 SE = 25.940

Arlington, WI

Y = 258.732 + 3.793H + 4.284H^2 + 0.355H^3
R^2 = 0.85 SE = 17.580

Figure 67. Regressions of acid detergent fiber (ADF) concentrations on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE = Square root of the residual mean square. The location by harvest interaction was significant at P = 0.0001 in both years.
Figure 68. Regressions of acid detergent lignin (ADL) concentrations on harvest for timothy in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
temperatures and precipitation were higher at Ames than at Arlington and Grand Rapids. In 1985, lignin concentrations increased at the highest rate over time at Rosemount, although lignin concentrations were comparable to those at Grand Rapids between harvests 3 and 8. Lignin concentrations were similar at Ames and Arlington and they increased at lower rates at most harvests compared with concentrations at Rosemount and Grand Rapids. Differential rates over time among locations likely were caused by differences in rainfall. Both Rosemount and Grand Rapids received more rain than Ames and Arlington in 1985 (Tables 5, 6, 7, and 8).

**Cultivar effects**

There was a significant cultivar effect for IVDMD, NDF, ADF, and ADL concentrations in 1984 and 1985 (Tables 40 and 41). Kämpe II had slightly higher average MSW values and IVDMD concentrations than Timfor in both years. Timfor had higher average NDF, ADF, and ADL concentrations in both years, whereas average N concentrations were similar between cultivars. A growth chamber experiment confirmed that Kämpe II had higher IVDMD concentrations than Timfor, but this was a result of Kämpe II being less mature. It is likely that Timfor had higher fiber concentrations than Kämpe II as a result of lower IVDMD concentrations. Results from the growth chamber experiment further indicated that Timfor partitioned more photosynthate than Kämpe II to herbage than to roots. Because fiber concentrations only were determined for herbage, differential partitioning of fiber between herbage and root could not be measured. Therefore, it is possible that cultivar differences might have been smaller had fiber concentrations been determined for both herbage and root material.
Table 40. Effects of timothy cultivars on MSW and concentrations of various quality factors in 1984 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW^a</th>
<th>IVDMD^b</th>
<th>NDF^c</th>
<th>ADF^d</th>
<th>ADL^e</th>
<th>N^f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timfor</td>
<td>42.2</td>
<td>649</td>
<td>588</td>
<td>334</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td>Kämpe II</td>
<td>42.8</td>
<td>660</td>
<td>579</td>
<td>326</td>
<td>34</td>
<td>21</td>
</tr>
<tr>
<td>Mean</td>
<td>42.5</td>
<td>655</td>
<td>584</td>
<td>330</td>
<td>35</td>
<td>21</td>
</tr>
<tr>
<td>SE^g</td>
<td>0.19</td>
<td>1.2</td>
<td>1.8</td>
<td>1.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>P&gt;F^h</td>
<td>0.0832</td>
<td>0.0002</td>
<td>0.0045</td>
<td>0.0016</td>
<td>0.0005</td>
<td>0.4932</td>
</tr>
</tbody>
</table>

^aMean stage by weight according to Simon and Park (1981).
^bIn vitro dry matter digestibility.
^cNeutral detergent fiber.
^dAcid detergent fiber.
^eAcid detergent lignin.
^fTotal Kjeldahl N.
^gStandard error of a cultivar mean. The MSW mean is based on 46 observations. All other means are based on 92 observations.
^hProbability of a larger F-value.
Table 41. Effects of timothy cultivars on MSW and concentrations of various quality factors in 1985 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW</th>
<th>IVDMD</th>
<th>NDF</th>
<th>ADF</th>
<th>ADL</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timfor</td>
<td>40.4</td>
<td>685</td>
<td>566</td>
<td>314</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>Kämpe II</td>
<td>40.7</td>
<td>692</td>
<td>562</td>
<td>307</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Mean</td>
<td>40.6</td>
<td>689</td>
<td>564</td>
<td>311</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>SE</td>
<td>0.13</td>
<td>1.2</td>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>P&gt;F</td>
<td>0.1191</td>
<td>0.0024</td>
<td>0.0312</td>
<td>0.0001</td>
<td>0.0389</td>
<td>0.3112</td>
</tr>
</tbody>
</table>

Mean stage by weight according to Simon and Park (1981).

^ In vitro dry matter digestibility.

^ Neutral detergent fiber.

^ Acid detergent fiber.

^ Acid detergent lignin.

^ Total Kjeldahl N.

^ Standard error of a cultivar mean. The MSW mean is based on 64 observations. All other means are based on 128 observations.

^ Probability of a larger F-value.
There was a significant location by cultivar interaction for IVDMD in 1984, and for MSW, NDF, and ADF in 1985 (Figs. 69, 70, 71, and 72). None of the interactions appeared to be biologically significant, however.

There was a significant cultivar by harvest interaction for ADL in 1984 and 1985, whereas only NDF and ADF concentrations were significant in 1985 (Figs. 73, 74, and 75). The NDF, ADF, and ADL concentrations tended to increase at higher rates over time for Timfor than for Kämpe II. Results from growth chamber experiments showed that Kämpe II had higher average IVDMD concentrations than Timfor, thus indicating that Timfor had higher fiber concentrations than Kämpe II. The cultivar by harvest interaction for IVDMD concentration was not significant, however.
Figure 69. Mean stage by weight values at three locations in 1984 and four locations 1985 as affected by two timothy cultivars. Each cultivar mean is based on eight harvests and two replications. The probability of a larger $F$-value ($P>F$) refers to the cultivar by location interaction. $SE =$ Square root of the residual mean square; $SE = NS$ when $P>F$ is greater than 0.05.
Figure 70. *In vitro* dry matter digestibility (IVDMD) concentrations at three locations in 1984 and four locations in 1985 as affected by two timothy cultivars. Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 71. Neutral detergent fiber (NDF) concentrations at three locations in 1984 and four locations 1985 as affected by two timothy cultivars. Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 72. Acid detergent fiber (ADF) concentrations at three locations in 1984 and four locations 1985 as affected by two timothy cultivars. Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 73. Regressions of neutral detergent fiber (NDF) concentrations on harvest for two timothy cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at \( P = 0.8886 \) in 1984 and \( P = 0.0002 \) in 1985. SE = Square root of the residual mean square.
Figure 74. Regressions of acid detergent fiber (ADF) concentrations on harvest for two timothy cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at $P=0.6100$ in 1984 and $P=0.0008$ in 1985. SE=Square root of the residual mean square.
Figure 75. Regressions of acid detergent lignin (ADL) concentrations on harvest for two timothy cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at \( P=0.0001 \) in 1984 and \( P=0.0030 \) in 1985. \( SE=\) Square root of the residual mean square.
Smooth Bromegrass - Field Study

'Barton' and 'Svaja' smooth bromegrass were grown at Ames IA, Arlington WI, Rosemount MN, and Grand Rapids MN. Because of difficulty in establishment, smooth bromegrass was absent from Rosemount in 1984. Smooth bromegrass was present at all locations in 1985, however. Deer grazing at Arlington resulted in poor stands of Svaja in 1984. Results of maturity, IVDMD, NDF, ADF, ADL, and N concentrations will be discussed in relation to locations, harvests, and cultivars.

Location effects

There was a significant location effect on mean values over harvests and cultivars for NDF, ADF, ADL, and N concentrations in 1984 and 1985. There was a significant location effect for MSW in 1985 and IVDMD in 1984 (Tables 42 and 43).

Mean stage by weight values for smooth bromegrass were higher at Grand Rapids and Ames than at Arlington in 1984. Smooth bromegrass likely had lower maturity stages at Arlington than at the other locations as result of deer grazing before sampling. In 1985, smooth bromegrass was most mature at Rosemount and least mature at Grand Rapids. High temperatures and moderate rainfall probably resulted in high MSW values at Rosemount, whereas low MSW values at Ames likely were a result of severe drought.

The NDF, ADF, and ADL concentrations tended to be higher at locations where smooth bromegrass was more mature and less digestible in both years. Nitrogen concentrations also tended to be lower at locations where smooth bromegrass was more mature. In 1985, Grand Rapids had the lowest maturity stage and lowest N concentration among locations.
Table 42. Stage of maturity and concentrations of various quality factors for smooth bromegrass grown at three locations in 1984

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW a</th>
<th>IVDMD b</th>
<th>NDF c</th>
<th>ADF d</th>
<th>ADL e</th>
<th>N f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>52.2</td>
<td>603</td>
<td>608</td>
<td>366</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>54.2</td>
<td>615</td>
<td>580</td>
<td>346</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>41.6</td>
<td>653</td>
<td>570</td>
<td>330</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Mean</td>
<td>49.3</td>
<td>624</td>
<td>586</td>
<td>347</td>
<td>37</td>
<td>23</td>
</tr>
<tr>
<td>SE g</td>
<td>3.43</td>
<td>3.0</td>
<td>4.6</td>
<td>3.8</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>P&gt;F h</td>
<td>0.0944</td>
<td>0.0001</td>
<td>0.0006</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0275</td>
</tr>
</tbody>
</table>

a Mean stage by weight according to Simon and Park (1981).
b In vitro dry matter digestibility.
c Neutral detergent fiber.
d Acid detergent fiber.
e Acid detergent lignin.
f Total Kjeldahl N.
g Standard error of a location mean. The MSW mean is based on 30 observations.

All other means are based on 61 observations.

h Probability of a larger F-value.
Table 43. Stage of maturity and concentrations of various quality factors for smooth bromegrass grown at four locations in 1985

<table>
<thead>
<tr>
<th>Location</th>
<th>MSW⁵</th>
<th>IVDMDB</th>
<th>NDF⁵</th>
<th>ADFD</th>
<th>ADLD</th>
<th>N⁷</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ames, IA</td>
<td>50.8</td>
<td>659</td>
<td>573</td>
<td>308</td>
<td>33</td>
<td>34</td>
</tr>
<tr>
<td>Rosemount, MN</td>
<td>54.3</td>
<td>629</td>
<td>606</td>
<td>334</td>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>Grand Rapids, MN</td>
<td>49.8</td>
<td>647</td>
<td>586</td>
<td>331</td>
<td>34</td>
<td>23</td>
</tr>
<tr>
<td>Arlington, WI</td>
<td>51.5</td>
<td>650</td>
<td>589</td>
<td>323</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>Mean</td>
<td>51.6</td>
<td>646</td>
<td>589</td>
<td>324</td>
<td>33</td>
<td>28</td>
</tr>
<tr>
<td>SE⁴</td>
<td>0.61</td>
<td>7.2</td>
<td>7.0</td>
<td>5.6</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>P&gt;F⁶</td>
<td>0.0234</td>
<td>0.0644</td>
<td>0.0406</td>
<td>0.0270</td>
<td>0.0347</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

⁵Mean stage by weight according to Simon and Park (1981).
⁶In vitro dry matter digestibility.
⁷Neutral detergent fiber.
⁸Acid detergent fiber.
⁹Acid detergent lignin.
¹⁰Total Kjeldahl N.
¹¹Standard error of a location mean. The MSW mean is based on 32 observations. All other means are based on 64 observations.
There was a significant location by harvest interaction for MSW, IVDMD, N, NDF, ADF, and ADL in 1984 and 1985. Stage of maturity increased curvilinearly over time in 1984 and 1985 (Fig. 76). In 1984, smooth bromegrass matured at higher rates over time at Ames and Grand Rapids than at Arlington. Stands of smooth bromegrass were weakened at Arlington as a result of deer grazing. This also could be seen by an initial lag in development. Smooth bromegrass matured at higher rates over time at Ames than at Grand Rapids. This was probably a result of higher temperatures at Ames (Tables 5 and 8). In 1985, smooth bromegrass matured at comparable rates between harvests 1 and 6 at Ames and Arlington, after which maturity continued to increase at Ames, but decreased at Arlington. Rates were comparable over all harvests at Rosemount and Grand Rapids, although rates tended to be lower than those at Ames and Arlington. Apparently, the hot and dry weather at Ames did not have a significant negative effect on smooth bromegrass development.

The IVDMD concentrations of smooth bromegrass decreased linearly over time in 1984 and 1985 (Fig. 77). The range in IVDMD concentrations over time tended to be lower in 1985 than in 1984, whereas differences between locations tended to be similar in both years. In 1984, digestibility of bromegrass decreased at the highest rate at Arlington and at lower, but comparable rates at Ames and Grand Rapids. The higher rate of decline over time at Arlington was unexpected because stage of maturity tended to increase at the lowest rate among locations. It is possible, however, that weakened stands resulted in poor growth of new plant material thereby resulting in herbage of low digestibility. In 1985, digestibility declined over time at the highest rate at Rosemount and at the lowest rate at Arlington. The IVDMD concentrations declined at comparable rates over time at Ames and Grand Rapids. Ames had low precipitation and high temperatures and Grand Rapids had high precipitation and low temperatures, factors that may explain the
Figure 76. Regressions of mean stage by weight values on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and two replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
Figure 77. Regressions of *in vitro* dry matter digestibility (IVDMD) concentrations on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE = Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0001$ in both years.
comparable rates of decline in digestibility. Rosemount had higher temperatures than Arlington, which likely caused the higher rates of decline in digestibility at Rosemount.

Nitrogen concentrations decreased curvilinearly over time (Fig. 78). Average N concentrations were higher in 1985 than in 1984 likely as a result of hotter and drier weather, which negatively affected growth. Because no yield data were recorded, it is difficult to interpret changes in N concentrations over time. In 1984, N concentrations were highest at Arlington followed by Ames and Grand Rapids. Nitrogen concentrations at both Arlington and Ames decreased between harvests 1 and 5 after which concentrations plateaued. Concentrations at Grand Rapids decreased in a nearly linear fashion throughout the harvest period. Lower temperatures and more mature smooth bromegrass at Grand Rapids compared with Ames and Arlington might have contributed to the lower N concentrations. The lower decline over time of N concentrations at Grand Rapids might have been caused by lower soil N levels. The Grand Rapids is sandier compared with the other locations. In 1985, N concentrations at each harvest were lowest at Grand Rapids, thus following the same trends as in 1984. Unlike results in 1984, however, smooth bromegrass at Ames generally had higher N concentrations than smooth bromegrass at Arlington, which probably was a result of droughty conditions at Ames.

The NDF and ADF concentrations changed linearly over time in 1984 and curvilinearly in 1985 (Figs. 79 and 80). Within years, NDF and ADF concentrations changed in a similar fashion, indicating that concentrations of hemicellulose changed similarly at each location. In 1984, NDF and ADF concentrations increased at the highest rates over time at Arlington, but at comparable rates at Ames and Grand Rapids. Thus, changes in NDF and ADF concentrations over time were the opposite of changes in IVDMD concentrations. In 1985, concentrations of NDF and ADF tended to increase at
Figure 78. Regressions of total nitrogen (N) concentrations on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
Figure 79. Regressions of neutral detergent fiber (NDF) concentrations on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. $SE=\sqrt{\text{residual mean square}}$. The location by harvest interaction was significant at $P=0.0001$ in both years.
Figure 80. Regressions of acid detergent fiber (ADF) concentrations on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE=Square root of the residual mean square. The location by harvest interaction was significant at P=0.0001 in both years.
the highest rate at Rosemount and the lowest rate at Arlington between harvests 1 and 4 and at the lowest rate at Ames between harvests 4 and 8. The changes in the rate of NDF and ADF concentrations over time tended to follow changes in maturity at Rosemount and Grand Rapids, but not at Ames and Arlington. It was not expected that rates of NDF and ADF deposition occurred at slower rates at Ames than at Arlington considering that temperatures were higher at Ames and that maturity stages showed a plateau at Arlington.

The ADL concentrations increased curvilinearly over time in 1984 and 1985 (Fig. 81). Lignin concentrations were higher and increased at higher rates in 1984 than in 1985 likely because of higher temperatures and drier weather. In 1984, ADL concentrations tended to increase at the highest rates over time at Grand Rapids and at the lowest rates at Arlington. These changes were consistent with changes in stage of maturity. In 1985, ADL concentrations increased at the highest rates over time at Rosemount and at the lowest rates over time at Ames. Hot and dry weather at Ames seemingly reduced the rate of ADL deposition over time.

Cultivar effects

The American cultivar of smooth bromegrass (Barton) had lower IVDMD and N concentrations, and higher NDF, ADF, and ADL concentrations because it was more mature than the Swedish cultivar (Svaja) (Tables 44 and 45). There was a significant location by cultivar interaction for MSW, and IVDMD only in 1985 (Figs. 82 and 83). Because results for MSW were inconsistent between locations and years, any interpretation of the cultivar by location interaction in 1985 is difficult. The cultivar by location interaction for IVDMD was caused by maturity differences between cultivars (data not shown).
Figure 81. Regressions of acid detergent lignin (ADL) concentrations on harvest for smooth bromegrass in 1984 and 1985. Data from each location were regressed on two cultivars and four replications in 1984 and 1985. Equations are listed in the same order as locations in legends. SE = Square root of the residual mean square. The location by harvest interaction was significant at $P=0.0106$ in 1984 and $P=0.0001$ in 1985.
Table 44. Effects of smooth bromegrass cultivars on MSW and concentrations of various quality factors in 1984 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW¹</th>
<th>IVDMD²</th>
<th>NDF³</th>
<th>ADF⁴</th>
<th>ADL⁵</th>
<th>N⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barton</td>
<td>50.6</td>
<td>612</td>
<td>597</td>
<td>355</td>
<td>39</td>
<td>22</td>
</tr>
<tr>
<td>Svaja</td>
<td>47.7</td>
<td>636</td>
<td>576</td>
<td>340</td>
<td>34</td>
<td>24</td>
</tr>
<tr>
<td>Mean</td>
<td>49.2</td>
<td>624</td>
<td>587</td>
<td>348</td>
<td>37</td>
<td>23</td>
</tr>
<tr>
<td>SE⁷</td>
<td>0.59</td>
<td>4.0</td>
<td>4.6</td>
<td>3.9</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>P&gt;F⁸</td>
<td>0.0163</td>
<td>0.0019</td>
<td>0.0100</td>
<td>0.0170</td>
<td>0.0008</td>
<td>0.0842</td>
</tr>
</tbody>
</table>

¹Mean stage by weight according to Simon and Park (1981).
²In vitro dry matter digestibility.
³Neutral detergent fiber.
⁴Acid detergent fiber.
⁵Acid detergent lignin.
⁶Total Kjeldahl N.
⁷Standard error of a cultivar. The MSW mean is based on 46 observations. All other means are based on 92 observations.
⁸Probability of a larger F-value.
Table 45. Effects of smooth bromegrass cultivars on MSW and concentrations of various quality factors in 1985 (means over locations and harvests)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>MSW&lt;sup&gt;a&lt;/sup&gt;</th>
<th>IVDMD&lt;sup&gt;b&lt;/sup&gt;</th>
<th>NDF&lt;sup&gt;c&lt;/sup&gt;</th>
<th>ADF&lt;sup&gt;d&lt;/sup&gt;</th>
<th>ADL&lt;sup&gt;e&lt;/sup&gt;</th>
<th>N&lt;sup&gt;f&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barton</td>
<td>52.7</td>
<td>624</td>
<td>608</td>
<td>339</td>
<td>36</td>
<td>25</td>
</tr>
<tr>
<td>Sveja</td>
<td>50.4</td>
<td>668</td>
<td>568</td>
<td>309</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>Mean</td>
<td>51.6</td>
<td>646</td>
<td>588</td>
<td>324</td>
<td>33</td>
<td>29</td>
</tr>
<tr>
<td>SE&lt;sup&gt;g&lt;/sup&gt;</td>
<td>0.25</td>
<td>2.2</td>
<td>1.9</td>
<td>1.6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>P&gt;F&lt;sup&gt;h&lt;/sup&gt;</td>
<td>0.0026</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mean stage by weight according to Simon and Park (1981).
<sup>b</sup>In vitro dry matter digestibility.
<sup>c</sup>Neutral detergent fiber.
<sup>d</sup>Acid detergent fiber.
<sup>e</sup>Acid detergent lignin.
<sup>f</sup>Total Kjeldahl N.
<sup>g</sup>Standard error of a location mean. The MSW mean is based on 64 observations.
<sup>h</sup>Probability of a larger F-value.

All other means are based on 128 observations.
Figure 82. Mean stage by weight values at three locations in 1984 and four locations 1985 as affected by two smooth bromegrass cultivars. Each cultivar mean is based on eight harvests and two replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
Figure 83. *In vitro* dry matter digestibility (IVDMD) concentrations at three locations in 1984 and four locations in 1985 as affected by two smooth bromegrass cultivars. Each cultivar mean is based on eight harvests and four replications. The probability of a larger F-value (P>F) refers to the cultivar by location interaction. SE=Square root of the residual mean square; SE=NS when P>F is greater than 0.05.
There was a significant cultivar by harvest interaction for ADL in 1984 and 1985. The interaction was significant for MSW, IVDMD, NDF only in 1985 (Figs. 84, 85, 86, and 87). Barton developed more rapidly than Svaja between harvests 1 and 3 after which Svaja developed at higher rates (Fig. 84). This indicates that Svaja was more dormant than Barton, but once dormancy was broken, it developed more rapidly.

Digestibility was lower and decreased more rapidly over time in Barton than in Svaja (Fig. 85). Analysis of variance by adjusting for stage of maturity revealed that the interaction was caused by Barton being more mature than Svaja (data not shown).

The NDF concentrations initially increased at higher rates in Barton than in Svaja (Fig. 86). At the final two harvests, however, rates of NDF deposition were higher in Svaja than in Barton. Analysis of variance by adjusting for stage of maturity revealed that the interaction was caused by Barton being more mature than Svaja (data not shown).

The ADL concentrations tended to be higher and increase at higher rates in 1984 than in 1985. Furthermore, Barton had higher ADL concentrations and a higher rate of increase over time than Svaja (Fig. 87). Because the cultivar by harvest interaction was not caused by differences in maturity (data not shown), different rates of lignin deposition were caused by genetic differences between the cultivars.
Figure 84. Regressions of mean stage by weight values on harvest for two smooth bromegrass cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at P=0.2465 in 1984 and P=0.0001 in 1985. SE=Square root of the residual mean square.
Figure 85. Regressions of *in vitro* dry matter digestibility (IVDMD) concentrations on harvest for two smooth bromegrass cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at P=0.0848 in 1984 and P=0.0001 in 1985. SE=Square root of the residual mean square
Figure 86. Regressions of neutral detergent fiber (NDF) concentrations on harvest for two smooth bromegrass cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at $P=0.3425$ in 1984 and $P=0.0288$ in 1985. SE=Square root of the residual mean square.
Figure 87. Regressions of acid detergent lignin (ADL) concentrations on harvest for two smooth bromegrass cultivars in 1984 and 1985. Data from each cultivar were regressed on three locations and four replications in 1984 and four locations and four replications in 1985. Equations are listed in the same order as cultivars in legends. The cultivar by harvest interaction was significant at $P=0.0057$ in 1984 and $P=0.0040$ in 1985. $SE=\text{Square root of the residual mean square}$
Implications of Results

Results from growth chamber and field experiments indicated that Swedish cultivars of alfalfa, red clover, timothy, and smooth bromegrass produced higher quality forage than American cultivars when compared under field conditions. Cultivars of red clover and timothy were more different than cultivars of alfalfa and smooth bromegrass. In the field experiments, red clover and timothy cultivars tended to be more different between locations and over harvests than cultivars of alfalfa and smooth bromegrass. In the growth chamber experiments, red clover cultivars were more different than timothy cultivars at the different daylengths, temperatures, and over time. Furthermore, differences in forage quality were not always related to differences in stage of maturity. This implies that there is a potential to incorporate "forage quality genes" from Scandinavian to Midwestern USA germplasm, which should result in high forage quality even as plants mature. The success of such plant breeding efforts and user acceptability will depend, however, on the potential of cultivars to produce high dry matter yields. Swedish cultivars in growth chamber experiments yielded less than American cultivars. Therefore, it is unlikely that midwestern forage producers will adopt the use of Scandinavian germplasm in its present form.
SUMMARY

A growth chamber study was undertaken to determine the response in plant mass, morphology, and quality to variation in daylength and temperature of two genetically diverse red clover and timothy cultivars. In a second study, changes in forage quality of two genetically diverse cultivars in each of alfalfa, red clover, timothy, and smooth bromegrass were studied in four different field environments in 1984 and 1985.

Growth Chamber Study

Stage of maturity increased with increasing daylength. Average stage of maturity increased 31% for red clover and 12% for timothy as daylengths were extended from 10 to 20 h. Most of the stimulation occurred between 10 and 15 h for timothy and between 15 and 20 h for red clover. The rate of maturation over time increased with increased daylength. Plateaus in development were reached earlier at long days than at short days, however. These results indicate that daylength extensions mainly act on shortening the life cycle, although the 10-h daylength apparently was too short to complete the life cycle in both species. Results further indicate that red clover has a higher critical photoperiod than timothy.

Average stage of maturity increased 21% for red clover and 9% for timothy as temperatures increased from 10 to 20 °C. At 20 °C, mean stage values increased curvilinearly over time, and the response was similar as that at the 20-h daylength treatment. At 10 °C, stages increased linearly for red clover and curvilinearly for timothy. Daylength had a larger effect than temperature on stage of maturity in both species. Temperature, however, had a larger effect on maturity in timothy than in red clover.
Red clover cultivars were more different in their responses to daylength and temperature than timothy cultivars. On average, Arlington was 18% more mature than Hermes II and Timfor was 7% more mature than Kämpe II. At 10 °C, American cultivars of both species reached reproductive stages 7 to 14 days earlier than Swedish cultivars at the 20-h daylength. Both species remained vegetative at 10 h and only American red clover reached reproductive stages at 15 h. At 20 °C, American red clover reached reproductive stages 7 to 14 days earlier than Swedish red clover at all daylengths. Timothy remained vegetative at 10 h. American timothy reached reproductive stages earlier than Swedish timothy at 15, whereas the reverse was true at 20 h. These results indicate that genetic differences were larger in red clover than in timothy, and that differences between cultivars diminished at longer days and higher temperatures.

Average plant height increased 17% for red clover and 32% for timothy when daylength was extended from 10 to 20 h. The daylength effect was not significant for either species, however. Plant height increased linearly over time at increasingly higher rates as daylengths increased, indicating that plant height continued to increase even when plateaus in development were reached. Thus, supplemental radiation had a stronger effect on height than a critical photoperiod.

Average plant height increased 19% for red clover and 34% for timothy as temperatures increased from 10 °C to 20 °C. The temperature effect was more significant for timothy than for red clover. Plant height increased curvilinearly over time at all temperatures. At 20 °C, plant height increased followed by a plateau, whereas at 10 °C plant height initially lagged followed by an increase. Thus, plant height followed changes in stage of maturity.

Arlington red clover was 13% taller than Hermes II red clover, but timothy cultivars did not differ in height. Arlington also increased at approximately twice the rate of Hermes II as daylengths were extended from 10 to 20 h.
Tiller number was not significantly affected by daylength in red clover and timothy, although timothy tended to have more tillers with increased daylength. Tiller number decreased 22% for red clover and 11% for timothy as temperature increased from 10 to 20 °C. Tiller number increased linearly over time and at higher rates at 10 °C than at 20 °C.

Red clover cultivars had similar tiller number, whereas American timothy had more tillers than Swedish timothy. Because northern cultivars generally produce more tillers than southern cultivars at comparable maturity stages, it was unexpected that Timfor produced more tillers than Kämpe II.

Leaf areas of both species increased when daylengths were extended. When daylengths increased from 10 to 20 h, leaf area of red clover increased 66% and leaf area of timothy increased 46%. Average leaf areas increased more between 10 and 15 h than between 15 and 20 h in both species. Leaf areas increased linearly over time with extended daylengths, but trends differed. The rate of leaf-area increase was similar at each daylength in timothy, whereas rates were higher at 15 and 20 h than at 10 h for red clover.

A temperature increase from 10 to 20 °C increased leaf areas in red clover by 18% and timothy by 56%. The temperature effect was significant for timothy, but not for red clover. Leaf areas of red clover increased linearly over time and at higher rates at 10 °C than at 20 °C, however. Leaf areas were higher at 20 °C than at 10 °C until maturity stages plateaued. The lack of daylength and temperature by harvest interactions for timothy indicates that leaf area of timothy is less affected by maturity changes than red clover. This was likely a result of higher degrees of senescence and leaf drop in red clover than in timothy.

Timfor timothy had higher leaf areas than Kämpe II because Timfor was more mature than Kämpe II. Arlington red clover had higher leaf areas than Hermes II, but differences were not statistically significant.
A daylength increase from 10 to 20 h increased specific leaf weight in red clover by 21% and timothy 4%. A 10 °C increase had the opposite effect of daylength, which indicates that daylength promotes deposition of nonstructural carbohydrates, whereas temperature promotes deposition of structural carbohydrates.

American cultivars of both species had lower specific leaf weights than Swedish cultivars as a result of more advanced maturity.

Root weights for both species were higher and increased at higher rates over time at 15 and 20 h than at 10 h. Root weights were highest at 15 h for timothy and highest at 20 h for red clover at all harvests. Because root weight of timothy at 10 h initially lagged followed by an increase indicates root reserves were used to produce leaf and shoot. Root weights increased at comparable rates over time at 10 and 20 °C in both species, but average weights were lower at 20 than at 10 °C.

Shoot weights of both species increased linearly over time and at increasingly higher rates as daylengths were extended. Shoot weights increased more between 10 and 15 h for timothy and shoot weights increased more between 15 and 20 h for red clover. Shoot weights were higher and increased over time at higher rates at 20 °C than at 10 °C for red clover. Shoot weights were slightly lower at 20 °C than at 10 °C, but changed at comparable rates over time for timothy.

Leaf weights increased linearly over time for red clover and curvilinearly for timothy. Leaf weights of red clover were lowest and increased over time at the lowest rates at 10 h. Rates were similar at 15 and 20 h, but absolute weights were highest at 20 h. Leaf weights of timothy at 20 h increased at high rates between harvests 2 and 5 after which weights plateaued. The plateau was likely caused by advanced maturity and senescence of leaves because plants at 10 h and 15 h, which were less mature, continued to gain weight. Average leaf weights of red
clover and timothy were higher at 20 °C than at 10 °C. Leaf weights of red clover increased at higher rates at 10 °C than at 20 °C. Leaf weights of timothy changed at similar rates at both temperatures over time.

Leaf:stem ratios decreased over time at 20 h, increased at 10 h, and remained relatively stable at 15 h for both red clover and timothy. Thus, shoots are produced at the expense of leaves as daylengths increase. Average leaf:stem ratios increased for timothy as temperatures increased, and decreased for timothy as temperature increased. Leaf:stem ratios for red clover decreased linearly over time at 20 °C, but changed curvilinearly over time at 10 °C, at which ratios increased followed by a plateau and a decrease. There was no significant temperature by harvest interaction for timothy for leaf:stem ratio.

Shoot:root ratios remained constant over time at 10 h, which indicates that shoots and roots were produced at comparable rates. At 20 h, the shoot:root ratios initially increased over time followed by a plateau. At 15 h, shoot:root ratios lagged followed by an increase for red clover, indicating that the shoot weight lag at 15 h compared with 20 h was the result of lower maturity stages. Average shoot:root ratios increased with increased temperatures in both species. There was no temperature by harvest interaction for timothy, but shoot:root ratios increased curvilinearly over time at both temperatures for red clover. At 10 °C, ratios initially lagged followed by an increase, whereas at 20 °C, ratios initially increased followed by a plateau.

When plant parts were calculated as a portion of total weight, shoots were produced at the expense of roots, whereas leaf percentage remained constant as daylengths increased. Shoots also were produced at the expense of roots as temperatures increased for red clover, whereas leaves were produced at the expense of roots for timothy.

American cultivars of both species had higher shoot and leaf weights, and higher shoot:root ratios than Swedish cultivars. Swedish cultivars had higher root
weights and leaf:stem ratios than American cultivars. Differences except for shoot:root ratios were caused by American cultivars being more mature than Swedish cultivars. Shoot weight increased more with increased daylength for Arlington than for Hermes II, whereas the reverse was true for root weight. Leaf weight increased with temperature for Hermes II, whereas no change was seen in Arlington. The leaf:stem ratio was higher and decreased less for Hermes II than for Arlington as temperatures increased. Growth of timothy cultivars did not change differently with increases in daylength and temperature.

Average N concentrations decreased with increased daylength, whereas N concentrations increased over time, but at rates that were similar between daylengths. Average IVDMD concentrations were not affected by increased daylengths, but over time, concentrations decreased at 20 h, increased at 10 h, and remained relatively constant at 15 h. The IVDMD effects likely were caused by increased leaf:stem ratios at 10 h and decreased leaf:stem ratios at 20 h.

Average N concentrations were not affected by temperature, whereas IVDMD concentrations decreased with increased temperature. Rates of change in N concentrations were different at 10 °C and 20 °C for red clover, but not for timothy. The N concentrations increased at higher rates at 10 °C than at 20 °C. The IVDMD concentrations changed linearly over time for red clover and curvilinearly over time for timothy at each temperature. Concentrations tended to fluctuate less over time at 20 °C than at 10 °C in both species.

American cultivars had lower IVDMD and N concentrations than Swedish cultivars. Differences between cultivars likely were a result of differential partitioning of photosynthate to plant parts as seen by higher leaf:stem and lower shoot:root ratios for the Swedish cultivars compared with the American cultivars.
Field Study

Stage of maturity and quality of alfalfa, red clover, timothy, and smooth bromegrass differed among locations as a result of different environmental conditions. Locations where species were more mature generally had lower IVDMD concentrations and higher NDF, ADF, and ADL concentrations. Nitrogen concentrations generally were lower at locations where plants were more mature.

Average maturity stages were similar between years for alfalfa and smooth bromegrass, but red clover and timothy had lower average maturity stages in 1985 than in 1984. Differences in maturity between locations tended to be larger in 1985 than in 1984, which probably was a result of hot and dry weather at all locations except at Grand Rapids in 1985. Mean stage by weight increased curvilinearly over time in both years, but trends differed between locations. In 1984, average stage of maturity for legumes was higher at locations receiving high temperatures. Grasses tended to reach higher maturities at locations with lower temperatures. Stage of maturity increased at the highest rate over time for both grasses and legumes at Ames, where weather was warmer and drier compared with the other locations. In 1985, maturity of legumes and grasses tended to be highest at Rosemount and lowest at Ames. Although the rate of increasing maturity over time was inconsistent between species and locations, alfalfa and smooth bromegrass tended to be least affected by the hot and dry weather at Ames compared with red clover and timothy.

Average IVDMD concentrations were higher in 1985 than in 1984 for all species except alfalfa, which had higher concentrations in 1984. Concentrations of IVDMD also were more different between locations in 1985 than in 1984, probably because of hot and dry weather in 1985. In 1984, IVDMD concentrations for alfalfa and timothy declined at the highest rate at locations where maturity increased the most over time. The rate of decline in IVDMD concentrations over time was
variable for red clover and smooth bromegrass in 1984. This may be a result of
one red clover cultivar being absent from Rosemount and both smooth
bromegrass cultivars being weakened by deer grazing at Arlington. In 1985,
IVDMD concentrations for legumes increased between harvests 1 and 3 followed
by a decline despite a continuous increase in stage of maturity. Higher than
normal temperatures might have resulted in higher leaf:stem (Faix, 1974) at the
initial harvests, thus explaining why digestibility increased simultaneously with
increased maturity.

Average N concentrations for red clover, timothy, and smooth bromegrass
were lower in 1984 than in 1985, whereas concentrations were similar between
years for alfalfa. Changes in N concentrations over time differed between
locations. Nitrogen concentrations generally were lower and decreased at the
highest rates at locations where plants had the highest maturity and where
advancement of maturity was the highest over time. These results indicate that N
dilution occurred as a consequence of high maturity and rapid development.

Average NDF, ADF, and ADL concentrations tended to be higher and to
decrease at higher rates in 1984 than in 1985. These results likely were caused by
hot and dry weather in 1985. In 1984, concentrations tended to increase at the
highest rate over time at Arlington and at the lowest rate at Ames for red clover,
timothy, and smooth bromegrass. Plants grown at Ames were expected to have
higher NDF, ADF, and ADL concentrations because of high temperatures. The rate
of change in NDF, ADF, and ADL concentrations tended to follow rates of maturity
increases over time, however. In 1985, concentrations of NDF, ADF, and ADL
tended to increase at the highest rate over time at Rosemount for all species. High
temperatures in conjunction with moderate rainfall likely resulted in high growth
rates and increased rates of fiber deposition. Changes in fiber deposition also
followed changes in stage of maturity over time. Rates of change in NDF, ADF,
and ADL concentrations for red clover, timothy, and smooth bromegrass tended to
be lowest over time at Ames. This likely was a result of hot and dry conditions at Ames. Concentrations of ADL tended to be more affected by hot and dry weather than concentrations of NDF and ADF.

American cultivars of red clover, timothy, and smooth bromegrass had lower average IVDMD concentrations and higher average NDF, ADF, and ADL concentrations because American cultivars were more mature than Swedish cultivars. Average maturity and concentrations of IVDMD, NDF, ADF, ADL, and N were not different between alfalfa cultivars. Swedish cultivars tended to have higher average N concentrations than American cultivars.

American and Swedish cultivars differed in their responses to maturity and forage quality at the different locations. Differences between cultivars were smaller in 1984 than in 1985 and red clover cultivars tended to be more different between locations than cultivars of the other species. In 1985, Hermes II red clover had lower maturity and higher concentrations of N, NDF, and ADF than Arlington red clover. Differences between cultivars were larger at locations that were hot and dry, however.

Stage of maturity, and concentrations of IVDMD, NDF, ADF, and ADL changed differently in red clover and timothy cultivars over time. American cultivars generally developed at higher rates than Swedish cultivars and as a consequence, concentrations of IVDMD decreased and concentrations of NDF, ADF, and ADL increased more rapidly over time for American than for Swedish cultivars. Rate of development and the change in forage quality over time were not different between cultivars of alfalfa and smooth bromegrass.
CONCLUSIONS

Increased daylengths and temperatures promoted maturity and total dry matter, although leaf and shoot weight were relatively more promoted than root weight. Maturity and plant mass were more affected by daylength than by temperature, likely because red clover and timothy appeared water stressed in chambers having high temperatures.

Maximum stimulation of maturity and plant mass required longer days for red clover than for timothy. This indicates that red clover has a higher critical photoperiod than timothy. Similarly, shorter days stimulated maturity and growth of American cultivars relatively more than Swedish cultivars. Field experiments also confirmed these findings.

Red clover cultivars were genetically more diverse than cultivars of alfalfa, timothy, and smooth bromegrass. Red clover cultivars differed more than cultivars of the other species in their response to daylength and temperature in controlled environments and to environmental field conditions.

Timothy and smooth bromegrass were more tolerant to lower temperatures than alfalfa and red clover. Grasses generally were more mature and had a higher rate of development at locations where temperatures were low, whereas legumes were more mature at locations with higher temperatures.

Alfalfa and smooth bromegrass were more drought tolerant than red clover and timothy. Alfalfa and smooth bromegrass were negatively affected by droughty conditions in 1985, but they were more mature and developed faster compared with red clover and timothy at locations that were dry.

Increased dry matter and advanced maturity resulted in diluted concentrations of N and IVDMD, whereas concentrations of NDF, ADF, and ADL increased. The range and the rate of change over time of these concentrations tended to be lower when conditions were hot and dry.
LITERATURE CITED


ACKNOWLEDGEMENTS

After nine years in the United States I will go back to Sweden with the feeling that Americans are "great". I will leave these people, many of whom are my closest friends, with great sadness. However, I also leave with enthusiasm for the challenges that are awaiting me at home.

There are numerous people who have meant a lot to me during my stay in the United States. Walter Wedin, my adviser, has been a steady support for me in the past six years. Dr. Wedin has been more personally involved and concerned about me and my fellow students than any other adviser I have met. His enthusiasm and sense of humor made life so much more enjoyable, especially during those otherwise dull field trips to the outlying research centers.

Antonio Mallarino has not only been a close friend, but also a second "major professor" after Dr. Wedin retired in 1989. Antonio is the kind of person who takes time to help other people even at times when he is busy and under a great deal of pressure. His sharp scientific mind and constructive suggestions were invaluable in the final development of my dissertation.

I wish to extend my gratitude to the members of my committee: Drs. Irvin Anderson, Alfred Blackmer, Dwayne Buxton, and David Glenn-Lewin. Their guidance and suggestions were appreciated.

Work efforts by other scientists were greatly appreciated. Doctors Craig Sheaffer, department of Agronomy and Plant Genetics at the University of Minnesota, and Rick Walgenbach, US Dairy Forage Research Center, Madison Wisconsin, who were responsible for the data collection in Minnesota and Wisconsin, respectively. Doctors Paul Hinz and David Cox who were among the finest professors I have ever had. They made statistics enjoyable by teaching it at a level that was understandable to most students.
Trish Patrick is every research leader's dream as an employee. She is organized, intelligent, and above all likeable. She made work so much easier for all of us.

My room mates Brian Diers and Ramon Gatnau will be greatly missed. Hopefully Brian's eagerness to travel will bring him to Sweden soon. Because Ramon is from a place in the sun, he is likely to be visited soon.

There are many more people to mention, but the ones who have been most important to me in the past few years include: Josefina D'Andrea, Myldred Wilson, Jim and Karol Wolff, Gordon and Lois Diers, Bo and Margareta Crabo, John Sagness, Philippe Detilleux and Johann Dubois, Matt and Vicky Sanderson, Mohammed "Big Mo" El-Mourid, Ivan Kangrga, Sabine Pestlin, Dale and Nancy Farnham, Emilio and Naomi Oyarzabal, Kent Short, Peter Lynch, Elisabet Thorstensson, Cindy Accola, Emma Mallarino, and Paul and Jenny Keim.

Finally I wish to express my sincerest thanks to my father and mother, Bertil and Mary-Anne, brother and sister, Thomas and Carina, and my grand mother, Edith. They have given me moral support and patiently waited for me to come back to Sweden.
APPENDIX

Table A1. Analysis of variance table for each species of red clover and timothy in growth chamber experiment

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>1</td>
</tr>
<tr>
<td>Chamber</td>
<td>5</td>
</tr>
<tr>
<td>Temperature (T)</td>
<td>(1)</td>
</tr>
<tr>
<td>Daylength (D)</td>
<td>(2)</td>
</tr>
<tr>
<td>T X D</td>
<td>(2)</td>
</tr>
<tr>
<td>Error (a)</td>
<td>5</td>
</tr>
<tr>
<td>Cultivar (Cv)</td>
<td>1</td>
</tr>
<tr>
<td>Harvest (H)</td>
<td>5</td>
</tr>
<tr>
<td>H X T</td>
<td>5</td>
</tr>
<tr>
<td>H X D</td>
<td>10</td>
</tr>
<tr>
<td>H X D X T</td>
<td>10</td>
</tr>
<tr>
<td>Cv X H</td>
<td>5</td>
</tr>
<tr>
<td>Cv X T</td>
<td>1</td>
</tr>
<tr>
<td>Cv X D</td>
<td>2</td>
</tr>
<tr>
<td>Cv X H X D</td>
<td>10</td>
</tr>
<tr>
<td>Cv X H X T</td>
<td>5</td>
</tr>
<tr>
<td>Cv X H X D X T</td>
<td>10</td>
</tr>
<tr>
<td>Error (b)</td>
<td>429</td>
</tr>
<tr>
<td>Total</td>
<td>504</td>
</tr>
</tbody>
</table>
Table A2. Analysis of variance table for each species of alfalfa, red clover, timothy, and smooth bromegrass in field experiments in 1984 and 1985

<table>
<thead>
<tr>
<th>Source</th>
<th>Df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (Loc)</td>
<td>3</td>
</tr>
<tr>
<td>Rep(Loc) [Ea]</td>
<td>12</td>
</tr>
<tr>
<td>Cultivar (Cv)</td>
<td>1</td>
</tr>
<tr>
<td>Loc*Cv</td>
<td>3</td>
</tr>
<tr>
<td>Rep*Cv(Loc) [Eb]</td>
<td>12</td>
</tr>
<tr>
<td>Harvest (H)</td>
<td>7</td>
</tr>
<tr>
<td>(H_{\text{lin}})</td>
<td>(1)</td>
</tr>
<tr>
<td>(H_{\text{quad}})</td>
<td>(1)</td>
</tr>
<tr>
<td>(H_{\text{cubic}})</td>
<td>(1)</td>
</tr>
<tr>
<td>(H_{\text{lof}})</td>
<td>(4)</td>
</tr>
<tr>
<td>Loc*H</td>
<td>21</td>
</tr>
<tr>
<td>( Loc*H_{\text{lin}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc*H_{\text{quad}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc*H_{\text{cubic}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc*H_{\text{lof}})</td>
<td>(12)</td>
</tr>
<tr>
<td>Cv*H</td>
<td>7</td>
</tr>
<tr>
<td>( Cv*H_{\text{lin}})</td>
<td>(1)</td>
</tr>
<tr>
<td>( Cv*H_{\text{quad}})</td>
<td>(1)</td>
</tr>
<tr>
<td>( Cv*H_{\text{cubic}})</td>
<td>(1)</td>
</tr>
<tr>
<td>( Cv*H_{\text{lof}})</td>
<td>(4)</td>
</tr>
<tr>
<td>Loc<em>Cv</em>H</td>
<td>21</td>
</tr>
<tr>
<td>( Loc<em>Cv</em>H_{\text{lin}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc<em>Cv</em>H_{\text{quad}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc<em>Cv</em>H_{\text{cubic}})</td>
<td>(3)</td>
</tr>
<tr>
<td>( Loc<em>Cv</em>H_{\text{lof}})</td>
<td>(12)</td>
</tr>
<tr>
<td>Residual [Ec]</td>
<td>168</td>
</tr>
</tbody>
</table>

Total                          | 255|