AN ABSTRACT OF THE THESIS OF

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Title Factors affecting establishment, survival, and production of birdsfoot trefoil (Lotus corniculatus L.) and alfalfa (Medicago sativa L.)

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Field, greenhouse, growth chamber and laboratory experiments evaluated factors affecting establishment, survival and production of birdsfoot trefoil (*Lotus corniculatus* L.) and alfalfa (*Medicago sativa* L.)

Field studies investigated the effects of a barley companion crop, seedling year harvest management and nitrogen and phosphorus fertilization upon stands, survival and subsequent production of legumes. Seedings were made in each of two years.

Stands of legumes were not affected by fertilization or harvest management, but decreased with increasing levels of companion crop competition. Death of seedlings occurred early in the establishment period and the degree of loss was similar for both species. Additional losses of plants did not occur during the establishment year. Losses of birdsfoot trefoil plants established with a companion crop occurred during the first winter following seeding. Stand reduction in the seeding year persisted for the duration of the experiment.

Companion crops inhibited the growth of surviving seedlings. Growth inhibition was less when barley was clipped periodically than when it was matured to grain. In the absence of a companion crop, growth of seedlings was inhibited more by frequent clipping of thin weed stands than by allowing weeds to mature.

Yields of weeds were inversely proportional to density of barley plants. Wild oats was more detrimental to seedling growth and was less readily controlled by clipping than redroot pigweed or pigeon grass.

The percentage of solar radiation intercepted by barley varied from 89 in early morning or late evening to 22 at noon. Light intensity was reduced more by barley in early season and less by barley in late season than by wild oats.

Yields of mixtures in the year after seeding were reduced as a result of establishment with a companion crop and to a greater degree and for a longer period of time when barley had been allowed to mature. Yield reductions of legumes were compensated for by increased grass yields. Grass grown with birdsfoot trefoil yielded significantly more in early season and significantly less in late season than grass grown with alfalfa.

Greenhouse studies evaluated the influence of soil temperature and phosphorus fertilization upon growth and phosphorus uptake of birdsfoot trefoil and alfalfa. Root growth of both species increased with increasing soil temperatures. Weight of alfalfa roots was twice that of birdsfoot trefoil at all temperatures. Top growth of birdsfoot trefoil increased to a greater degree than that of alfalfa with increasing temperature. The greater top growth of birdsfoot trefoil resulted in reduced root-shoot ratios. Birdsfoot trefoil produced less dry matter per $cm.^2$ of leaf area than alfalfa. Root growth of both species increased with increasing applications of P fertilizer. Phosphorus appeared to be more important to growth at low than at high temperatures. Phosphorus and nitrogen uptake by both species increased with increasing soil temperature.

Growth chamber studies evaluated the influence of low light intensities and seedling age upon growth of seedlings and distribution of accumulated dry matter. Seedlings gained weight at light intensities of 200 to 800 f.c. With decreasing light intensity, stem elongation occurred at the expense of roots. A smaller percentage of accumulated dry matter went into roots of two-week than in older seedlings. Roots of two-week old seedlings of alfalfa lost weight at 200 f.c.

Laboratory studies evaluated oxygen uptake of germinating birdsfoot trefoil and alfalfa seeds. Average oxygen uptake by both species on a per unit weight basis was similar. Alfalfa, due to its greater size, had a greater oxygen uptake on a per plant basis than did birdsfoot trefoil.

FACTORS AFFECTING ESTABLISHMENT, SURVIVAL, AND PRODUCTION OF BIRDSFOOT TREFOIL (*LOTUS CORNICULATUS* L.) AND ALFALFA (*MEDICAGO SATIVA* L.)

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INTRODUCTION

Birdsfoot trefoil (*Lotus corniculatus* L.) has been grown in small plantings in the British Isles and in western European countries for more than 100 years (27, p. 1-14). In the United States, however, it is a relatively new legume and extensive evaluation of its use for forage production has been confined to the last twenty years.

The promising qualities of birdsfoot trefoil were summarized from results of other workers by Midgley (29, p. 6-11) in 1951. He states that "(1) It is superior to alfalfa (*Medicago sativa* L.) on poorly drained clay soils, (2) it is better than Ladino clover (*Trifolium repens* L.) on drier lands, (3) it withstands closer grazing than alfalfa or most clover, and (4) it is less exacting in soil fertility or moisture requirements than other legumes, but, under proper conditions, produces excellent hay, pasture or silage." The main advantage of birdsfoot trefoil over other legumes is its non-bloating property. There has never been a case of bloat reported with animals grazing birdsfoot trefoil pasture.

Birdsfoot trefoil is rapidly gaining acceptance as a forage legume and is currently recommended in most states of the Northern United States (26, p. 2-35). One of the main objections to this legume in all areas is that it is slow to establish and is more sensitive to competition than other commonly recommended forage legumes. The poor competitive ability of this species has impeded acceptance.

Seedlings of birdsfoot trefoil may be expected to have to compete with other plants during the life of a stand. Establishment with a companion crop is desirable from the practical standpoint in that farmers do not have to experience the loss of one crop year. Being a pasture legume, it is most likely to be seeded with a grass which may not be competitive in the year of seeding but may be expected to be competitive in subsequent years. Even in pure stands the encroachment of weeds constitutes a competitive pressure.

Maximum effective utilization of this species will not be achieved unless a fuller understanding of the factors affecting its competitive ability is attained. Information is needed to delineate critical periods in the establishment of this species and to evaluate the effect of competitive pressures in the seedling year upon subsequent performance. Further evaluations of the role of specific growth factors during periods critical to establishment need to be made. Information obtained from such investigations may lead to development of cultural practices requisite to successful establishment and performance of birdsfoot trefoil.

During the period 1960-1963 a series of field, greenhouse, growth chamber and laboratory studies were conducted in an attempt to delineate periods critical to birdsfoot trefoil establishment and factors responsible for its poor competitive ability. In all studies alfalfa was included for comparative purposes, since it is the most widely grown legume in areas where birdsfoot trefoil is adapted.

REVIEW OF LITERATURE

Birdsfoot Trefoil as a Pasture Legume

The first results from grazing trials with birdsfoot trefoil in the United States were reported by Mott in 1946 (32, p. 31, 74-76). Since that time a number of comparisons of birdsfoot trefoil with other legumes have been made in both simulated and actual grazing trials. Yawalkar and Schmid (53, p. 407-411) report that birdsfoot trefoil contributes little to the yield of complex mixtures due to its poor competitive ability and state that if it is to be used for pasture, it should be seeded alone or with one grass. Most evaluation trials have been conducted on this basis.

Simple grass-legume mixtures containing birdsfoot trefoil were shown to be equal in some cases to those containing Ladino clover in simulated grazing trials in Montana and were superior where drought was a factor (10, p. 3-8). In grazing trials with sheep in Montana, under a 7-day on, 14-day off rotation system, animals gained more on a birdsfoot trefoil-grass mixture than on an alfalfa-grass mixture or on a Huntley mixture [orchardgrass (*Dactylis glomerata* L.), smooth bromegrass (*Bromus inermis* Leyss.), meadow fescue (*Festuca elatior* L.), Kentucky bluegrass (*Poa pratensis* L.), white clover (*Trifolium repens* L.) and alsike clover (*Trifolium hybridum* L.)] . On a 7-day on, 42-day off rotation, gains were similar on birdsfoot trefoil and alfalfa-grass mixtures and were superior to those of the Huntley mixture (18, In preparation).

Ladino clover-grass mixtures were higher yielding than birdsfoot trefoil-grass mixtures in the first year of a grazing trial with lambs in Ohio (12, p. 436-440). In the second and third years mixtures containing birdsfoot trefoil were higher yielding than those containing Ladino clover. In these trials, however, much of the Ladino clover was lost from drought. The advantage of birdsfoot trefoil over Ladino clover, under conditions of drought, was further borne out by trials in Montana (7, p. 180-183) in which Ladino clover was shown to respond much more readily to irrigation and to be more adversely affected by drought than birdsfoot trefoil.

In one Indiana grazing trial birdsfoot trefoil pastures were shown to be equal to an alfalfa-timothy pasture and superior to a bluegrass-clover pasture in pounds of beef produced per acre (32, p. 31, 74-76). In another trial a birdsfoot trefoil-grass mixture produced more beef per acre during a five-year period than bluegrass alone fertilized with 360 pounds of ammonium nitrate annually (33, p. 1-16).

Companion Crops and Legume Establishment

From the economic standpoint it is desirable to establish legumes with a companion crop to avoid the loss of one crop year. Companion crops, however, are, in general, detrimental to the welfare of the legume seedling.

The influence of companion crops and of various herbicide treatments on stand establishment and yields the year following treatment was studied by Sholl and Staniforth (47, p. 432-435). They reported excellent control of weeds with a combination of 4 pounds of Dalapon and ½ pound of 4(2,4-DB) per acre. Companion crops reduced stands and yields of birdsfoot trefoil under all managements studied; however, rainfall was a limiting factor in those years in which companion crops were seeded.

Companion crops may be expected to reduce the yields of legumes if seeded on a weed-free seed bed. However, where weeds are a problem, the weeds themselves may furnish as much competition as a companion crop. Smith *et al*. (50, p. 449-451) studied the influence of seeding rate of an oat (*Avena sativa* L.) companion crop on the establishment of legumes. On the heavy soils studied, weeds were prominent and increased as the seeding rate of oats decreased. Increased weed growth compensated for the decrease in oats as a competitive factor and, consequently, differences in stand establishment of legumes were only slightly affected by seeding rate of oats. On light soils competition for moisture appeared to be the major factor influencing the establishment of legumes. On these soils poor stands of legume occurred with heavy seeding rates of oats.

Seeding the companion crop at less than the normal rate or at wider row spacings seems to benefit the legume and often with little loss of grain yield. Pendleton and Dungan (40, p. 442-444) studied the influence of different spacings of an oat companion crop upon yields of oats and of red clover (*Trifolium pratense* L.). In no oat seeding arrangement did the red clover population, early growth, or hay yield equal that of plots where red clover was grown alone. The growth and hay yields of red clover were proportionately better as the spacing width increased. Grain yields ranged from 43.6 bushels an acre for the 24-inch spacings to 67.9 bushels for an 8-inch spacing.

Klebesadel and Smith (21, p. 627-630) found that stands of alfalfa were reduced when an oat companion crop was allowed to mature. Thinner stands, however, were not associated with yield reduction in subsequent years. Collister and Kramer (6, p. 385) found that different varieties of oats used as companion crops affected yield of red clover herbage. Oat height and yield of clover forage were negatively correlated. Smith _et al_. (50, p. 449-451) studied the effect of sowing rates of oats upon legume establishment. Differences in sowing rate were minimized due to increased weed growth on thinly sown oat plots. Oat varieties did not significantly affect legume stand.

In the companion crop experiments reported, the majority show that stands of legume were reduced with increasing levels of competition. In most cases decreases in stand were accompanied by decreases in yield. In these trials no attempt was made to delineate periods in which losses in stand occurred.

Competition and the Micro-environment

In legume seedling establishment, competition may be intentional (seeding with a companion crop) or non-intentional (ingress of weeds). In either case the growth rate of the companion crop or weeds will exceed that of the legume seedling and they may be considered as an overstory species. Competition may be defined as an adverse environmental condition for one plant brought about by the presence of another. Within this definition plants in a community may be mutually depressive, or an agressor species best adapted to a given environment may dominate. An adverse environmental condition may be manifest as a decrease in light, nutrients or moisture supply. It may also occur as a change in the macro-, micro- or bio-micro-climate, i.e. temperature. The effects of a change in environment at any level are seldom a result of one factor, but rather an interaction of factors. Optimum growth is attained when the most favorable balance of all environmental factors occurs.

Probably the most marked effect of an overstory species upon the micro-environment of an understory species is the reduction of light intensity. Since growth is dependent upon photosynthesis, reduction of light below levels needed for optimum photosynthesis restricts growth. When light is reduced to the point that photosynthesis equals respiration (light compensation point), growth cannot occur. Further reduction will result in a greater loss of substrate by respiration than is being synthesized and death of the seedling may occur.

Photosynthetic and respiratory rates vary with temperature. Optimum temperatures for photosynthesis are generally lower than those for respiration (11, p. 176). For example, photosynthetic rate in the white potato attained a maximum at about 20°C., but respiration at this temperature was only 12% of its maximum rate. When temperature was increased to 48°C. the rate of photosynthesis decreased to zero, but respiration rate reached the optimum (25, p. 70-77). Since growth of a plant is represented by the difference between synthesis and oxidation of organic compounds, plants are at a disadvantage when temperatures exceed the optimum for photosynthesis.

The variable effects of temperature on photosynthesis and respiration cause light measurement criteria such as "light compensation point" to fluctuate. Thus the quantity of light required for photosynthesis to equal or exceed respiration will vary with temperature. As a consequence, the influence of reductions in light intensity may be more critical at one period of growth than another.

Ormrod (37, p. 93-95) studied compensation points of rice seedlings as influenced by temperature. The compensation point increased with temperature and was 150 f.c. at 40^{o}F., 400 f.c. at 60^{o}F. and 1400 f.c. at 80^{o}F. He states that low temperature in the field at night may be beneficial due to low respiration and that high temperature with low light intensity may be serious in terms of net uptake or release of CO_2 by the plant.

Reduced light intensity may alter the ratio of plant organs. Blackman and Templeman (4, p. 533-587) report that at low light intensity, leaf production takes place at the expense of roots. Reduced root growth in turn increases the susceptibility of seedlings to drought (48, p. 523).

Rhykerd et al. (46, p. 199-201) found that birdsfoot trefoil had a very low proportion of leaves to stems at low light intensities as compared to red clover. They point out that this may be an important factor in explaining the lack of competitiveness of birdsfoot trefoil when it is established with a companion crop. In another study Rhykerd et al. (45, p. 7-9) found that birdsfoot trefoil fixed significantly less CO_2 under all light treatments tested than did red clover or alfalfa. McKee (26, p. 1-35) found that the leaf area per plant of

Pennscott red clover often increased under conditions of moderate shading. In contrast, leaf area of alfalfa remained constant and that of birdsfoot trefoil decreased.

Gist and Mott (17, p. 583-586) found that decreases in light intensity inhibited root and top growth of birdsfoot trefoil in much the same manner as for alfalfa and red clover. However, the growth of birdsfoot trefoil seedlings was only about one-third that of alfalfa under all light intensity treatments. McKee (26, p. 1-35) found that trefoils shaded for 5 weeks required 6 to 11 weeks of growth in full daylight to restore their original top/root ratio. He also reported that the dry-top-weight/leaf-area ratio for red clover and alfalfa was .011 and for trefoil was .017, which indicated that red clover and alfalfa accumulated less dry matter per unit of leaf area. Since weight of roots was not included in this calculation, the validity of his assumption is open to question.

Prichett and Nelson (41, p. 173-177) report that one of the most striking effects of reduced light intensity on alfalfa was the proportional decrease in nodulation. They found that nodulation essentially stops at less than 257 f.c. and state that this may be a contributing factor to loss of seedlings in the field. McKee (26, p. 1-35) reported that Vernal alfalfa and Empire and Viking birdsfoot trefoil required at least 25% of daylight to be functionally nodulated and 50% to be adequately nodulated. In contrast, functional nodules of Pennscott red clover were observed at 12.5% of full daylight.

An overstory species reduces the insolation intensity and influences the wavelength of radiation reaching the soil surface. Geiger

(16, p. 282) reported that the insolation intensity at the soil surface under plants one meter high in a meadow was only one-fifth that at the soil surface of bare ground. The wavelengths of radiation are also different since light reflectivity of plants is dependent upon wavelength. Reflectivity is in the range of 8-20% for wavelengths in the visible range of light but rises to 45% in the infra-red range (16, p. 272). Thus the intensity and quality of light reaching the soil surface differs under plant cover and may influence soil and air temperatures near the surface. Geiger (16, p. 287) points out that the intensity of incoming radiation upon a growing crop and bare soil is the same during the day. Likewise, the intensity of outgoing radiation at night is equal. The effect of the plant cover is on the distribution of heat gained or lost. Dense stands of plants result in a cooler air temperature near the ground during the day. At night, however, outgoing radiation is from the top surface of the vegetation and the air is consistently warmer near the ground.(16, p. 290). In contrast, in the absence of an overstory species, radiation is from the soil surface, resulting in a cooler layer of air near the ground.

Cooper and Ferguson (8, In press) found soil temperatures to be 3 to 8°F. lower under a barley companion crop at depths of 3 to 24 inches. Temperature is known to have marked effects on metabolic processes. As pointed out by Richards _et al_. (43, p. 303-480) "Such physiological phenomena as cytoplasmic streaming, bio-electric potential, synthesis of organic materials, translocation, and respiration are all influenced by temperature." The influence of soil temperature on plant growth has been studied by numerous workers. Most studies have emphasized the effect of soil temperature on ion absorption. Difficulties have been encountered in this respect in that it is not easy to separate temperature effects upon the absorption process from effects upon translocation and utilization of nutrients within the plant (39, p. 77-79).

Increasing soil temperatures have generally been shown, within limits, to increase the phosphorus content of plants. In a study of ryegrass (*Lolium perenne* L.) grown at temperatures of 10, 20 and 30°C. phosphorus content was highest at 20°C. and was higher at 30 than at 10°C. (38, p. 257-259). The percentage N, however, was less at 20 than at 10 or 30°C. Nielsen *et al*. (35, p. 369-371) measured P uptake of corn and bromegrass at soil temperatures of 41, 54, 67 and 80°F. In the absence of added phosphorus, the P content of both species increased with temperature. With added phosphorus, however, the concentration of P tended to decrease with increasing temperature. Apple and Butts (1, p. 325-332) found that applied phosphorus increased P content of pole beans significantly more at low than at high temperatures. The effect of temperature on P content was greatest when P was applied.

Eid *et al*. (14, p. 361-370) fertilized corn grown under soil temperatures of 20 and 35°C. with phosphorus at rates of 0, 150 and 300 pounds of P_2O_5 per acre. At 20°C. availability of soil P was determined almost entirely by the inorganic fraction. At 35°C. both organic and inorganic fractions were related to the amount of plant-available P. Differences between temperatures were not significant for inorganic fractions, but were highly significant for organic fractions. They attribute their results to rapid mineralization of the organic P fraction at high temperatures. Ketcheson (20, p. 41-47) found that phosphorus application decreased the P percentage in corn at higher temperatures but increased the P percentage at lower temperatures. The lower percentage at higher temperatures was attributed to the increased growth of herbage without additional absorption.

The effects of soil temperature on cation absorption have been more variable than that of phosphorus. Nielsen et al. (36, p. 287-292) studied cation absorption by alfalfa grown at soil temperatures of 5, 12.2, 19.6 and 26.7°C. Potassium increased in tops and decreased in roots with increasing soil temperatures. Both Mg and Ca content of roots and tops decreased with increasing temperature. Wallace (51, p. 407-411) found that K content of soybeans increased with increasing temperatures of 12, 22 and 32°C., while divalent cations decreased. In barley K increased from 12 to 22°C., but decreased from 22 to 32°C. Hoaglund and Broyer (19, p. 471-507) found the accumulation of K by cells, over short periods of time, was definitely related to temperature. Ehrler and Bernstein (15, p. 67-74) found that low root temperatures, in general, consistently resulted in lower levels of cations in rice at maturity. Miller and Army (31, p. 118-154) attribute increased K absorption with increasing temperature to higher metabolic activity. In general, it would appear that K absorption is increased while Ca and Mg are decreased with increasing temperature. Peterson and Krackenburger (39, p. 77-97) point out that changes in culture solution, to promote K absorption, will, in general, decrease absorption of Ca and Mg. It would seem that there is an inverse absorption relationship between these cations which is influenced by temperature, concentration and other factors.

The effects of plant cover on air and soil temperatures may alter the ratio of root to top growth since various organs of the same plant have different cardinal temperatures for the same functions (11, p. 177).

Ketcheson (20, p. 41-47) states, "If temperatures are below optimum, root growth may be inhibited due to reduced translocation of reserves, reduced nutrient uptake, or both."

Nielsen *et al*. (35, p. 369-371) found roots and tops of corn increased with temperatures of 41, 54, 67 and 80°F. Tops of bromegrass also increased with increasing temperature. Roots of bromegrass, however, increased from 41 to 67°F., but decreased from 67 to 80°F. Proebsting (42, p. 278-281) found top/root ratios of strawberry clover (*Trifolium fragiferum* L.) were lowest at low soil temperatures. Nielsen *et al*. (34, p. 255-263) found that top/root ratios of oats increased with temperatures from 41 to 80°F. McKell *et al*. (28, p. 109-113) found that either an increase in temperature or an increase in P fertility increased top/root ratios. In general, most results from soil temperature studies show that although growth of roots and tops are both promoted with increasing temperatures, the growth of tops is proportionately greater than that of roots.

Loomis (24, p. 197-217) states, "Correlations in the growth of roots and shoots are primarily competitive. Root growth tends to be limited by supplies of carbohydrate and other growth materials from the top, and growth of shoots is limited by supplies of water and minerals obtained through the roots." Since roots serve as the absorbing and storage organs of plants, culture conducive to their optimum growth during the establishment period should be of paramount importance to plant survival.

In addition to affecting light intensity and air and soil temperatures, an overstory species modifies atmospheric humidity. Plants retard the rate of evaporation from the soil and are themselves constantly exuding water vapor in transpiration. Furthermore, the overstory species retards the movement of wind, so that movement of water vapor from the plant surface is limited. The result of these influences is an increase in relative humidity within the vegetative cover (16, p. 279).

Aside from its effect upon the micro-environment, an overstory species competes directly with an understory species for soil moisture and nutrients. Roots of barley were shown to have penetrated to a depth of 6.6 inches and spread laterally to a width of 5.5 inches (8, In press) before legume seedlings were two inches high. Thus, if either soil nutrients or moisture were in scarce supply, direct competition by a companion crop for these factors could be critical very early in the establishment period.

From the foregoing discussion, it is evident that the introduction of competition with legume seedlings in the form of a companion crop or weeds results in a complicity of environmental changes. These changes in turn may have profound effects upon the photosynthetic-respiration balance within a plant.

Since environmental conditions vary with time, conditions for growth and factors affecting it vary with time. Thus, the growth of an individual species may be more critical at one phenological growth stage than at another. In studying factors affecting establishment and performance of a species, the first objective should be to delineate periods most critical to its growth. Once these periods are delineated, more detailed studies concerning specific environmental factors may be made.

AIM AND SCOPE OF STUDY

Field Studies

From the literature cited in the preceding section, two assumptions may be made with respect to establishment of legumes with companion crops. (1) Stands of legumes will be reduced and (2) subsequent performance of legumes may be impaired. In the studies previously reported, however, no attempt was made to determine the periods in which seedling loss occurred, nor whether or not subsequent performance of legumes was a result of reduced stands, reduced plant vigor, or both. In the field studies reported herein, the specific objectives were to determine (1) the effect of a companion crop upon stand loss and growth retardation of seedlings, (2) the most critical periods in establishment, (3) the effect of competition modification by cultural practice on seedling establishment, (4) the effect of reduced stands or retarded seedling growth upon subsequent performance of legumes grown in association with grass.

In considering the first two objectives, several assumptions may be made: (1) seedlings die prior to barley maturation due to competitive pressure from the companion crop, and (2) seedling loss may occur during periods subsequent to barley maturation due to growth inhibition during the establishment period.

Objective three assumes that the adverse effects of companion crops are in proportion to competitive pressure. Evaluation of this objective presupposes that through cultural practices the degree of competition may be modified or that the ability of the seedlings to withstand competition may be enhanced.

The fourth objective evaluates the long-range adverse effects of companion crops. The influence of stand losses upon subsequent legume performance might be expected to persist for the life of the stand or might be compensated for by increased size of plants with time in thinner stands. The effects of reduced seedling vigor would be expected to decrease with time unless the weakened condition of legume seedlings favored growth of the grass associate. In this case, the more vigorous growth of the grass associate might affect legume performance for longer periods. The inter-relationship of grass and legume yields as influenced by establishment practice is of particular interest from the standpoint of pasture production.

Soil Temperature Studies

In the field studies precise control and evaluation of specific growth factors such as light, temperature and moisture were not feasible. In order to evaluate the influence of some of these factors more precisely, additional studies were initiated. The first of these was to study the influence of soil temperature upon growth. Its objectives were to determine (1) the influence of soil temperature upon root and shoot development of birdsfoot trefoil and alfalfa and (2) the inter-relationships of phosphorus and soil temperature upon growth.

In considering objective one, it is assumed that part of the adverse effects of a companion crop may be due to a decrease in soil temperature. The effects of soil temperature on growth are thus of interest, particularly with respect to root growth. Rapid penetration of roots into soil enables seedlings to escape drought conditions which occur most readily in the surface soil. Furthermore, since roots serve as the storage reservoir for carbohydrates used in growth initiation, the following year, they are important to winter survival.

The relationship of phosphorus uptake of seedlings to soil temperature may be of particular importance in the Intermountain Region. Soil temperatures in early spring may be too low for mineralization of organic phosphorus. Thus seedlings may be dependent solely on inorganic phosphorus for growth. The availability and quantity of inorganic phosphorus and the ability of seedlings to take up phosphorus at specific temperatures would definitely influence the vigor and survival of seedlings.

Light Study

The second specific growth factor selected for study was light. Objectives of this study were to determine (1) the light compensation points of alfalfa and birdsfoot trefoil and (2) whether or not response of seedlings to low light intensity varies with age of seedling.

The objectives of this study assume that seedling loss in the field occurs prior to barley maturation and is due to reduced light intensity. Since death is assumed to occur at light intensities below compensation point, differences in this value between species could account for greater loss of one species than another. It is also assumed that compensation points may vary with seedling age. If this were the case, seedlings would be more susceptible to low light intensity at one age than another. Fulfillment of these objectives should clarify the effects of low light intensities on seedling growth.

Respiration Study

The fourth experiment was conducted in the laboratory with the sole objective of determining whether or not alfalfa and birdsfoot trefoil differ with respect to rate of respiration. Alfalfa generally is considered to have greater seedling vigor and is more productive than birdsfoot trefoil. Although the difference in growth potential of these two species is genetic in nature, its manifestation may be due to a more efficient metabolic rate. Measurements of respiration rates of germinating seeds of these species should provide information on their metabolic activity.

FIELD STUDIES--INFLUENCE OF COMPANION CROP, SEEDING YEAR MANAGEMENT AND FERTILIZATION PRACTICE UPON THE ESTABLISHMENT, SURVIVAL AND PERFORMANCE OF BIRDSFOOT TREFOIL AND ALFALFA

DESCRIPTION OF AREA

The experiment was conducted at the Crops and Soils Field Research Laboratory of Montana Agricultural Experiment Station, located five miles west of Bozeman, Montana, at a latitude of 46° N and a longitude of 111° E, at an elevation of 4800 feet. The farm is typical of irrigated land in Gallatin Valley, Montana. Crops in this region are mostly small grains, alfalfa hay, and irrigated pasture. There is some production of small-seeded legume seed, mostly sweet and red clover.

The climate of the area is typical of the Intermountain Region with harsh winters and cool summers. The average duration of the frost-free period is 116 days. Precipitation and average mean maximum and minimum temperatures for 1960-1962 crop years are presented in Table 1. Since the Field Laboratory was recently established, long-time records are not available for comparative purposes.

The soil on the farm is Bozeman silt loam, brown-phase, which is characterized as follows:

Depth	Description
0 to 6 inches	Dark grayish-brown, friable, silt-loam of fine-crumb structure; about neutral.
6 to 12 inches	Grayish-brown, friable, moderately heavy silt-loam; indistinct prismatic structure, about neutral.

Table 1. Mean monthly precipitation and maximum, minimum temperatures at the Agronomy Farm, Bozeman, Montana, 1960-1962.*

	Precipitation by years in inches			Mean temperature by years in °F.					
	59-60	60-61	61-62	59-60		60-61		61-62	
				Max.	Min.	Max.	Min.	Max.	Min.
Nov.	.68	.33	.88	41.4	13.8	43.2	21.8	40.3	14.9
Dec.	.42	.39	.20	37.8	14.1	36.4	10.9	31.2	11.5
Jan.	.32	.01	1.21	29.5	4.9	38.7	14.1	26.2	.5
Feb.	.25	.51	.70	31.5	7.4	45.6	26.0	32.9	10.6
March	1.43	.39	.83	42.5	17.4	48.6	22.9	40.1	14.8
April	1.80	1.40	.86	52.4	28.2	52.2	27.4	59.4	30.7
May	1.98	1.48	3.11	63.5	34.9	66.3	36.5	61.8	37.0
June	1.10	.60	1.61	75.2	43.2	80.9	46.3	72.5	43.1
July	.15	.61	4.21	86.1	49.4	84.4	48.3	78.4	47.0
Aug.	1.79	.61	1.63	79.8	44.7	85.6	48.1	77.2	45.4
Sept.	.32	4.15	.51	72.5	37.7	60.3	33.2	69.1	36.1
Oct.	.65	1.65	1.22	60.3	31.2	54.8	26.2	62.1	34.4
Total	10.89	12.13	16.97						

* Growing season climatic data for a crop year is considered to be those precipitation and temperature data commencing in November of the preceding year and continuing through October of the crop year.

12 to 20 inches	Yellowish-brown or light-brown, friable, silty, clay loam; slightly alkaline.
20 inches plus	Light-gray, highly calcareous silt-loam; locally contains some fine sand. Underlain at 3 or more feet by stratified sands and silts.

The surface soil is considered to be low in organic matter and phosphorus and is approximately neutral in pH.

EXPERIMENTAL PROCEDURE

Birdsfoot trefoil-orchardgrass and alfalfa-orchardgrass mixtures were established under three companion crop treatments and two rates of nitrogen and of phosphorus fertilization. Mixtures established under the above treatments were further subjected to two harvest management treatments in the year of seeding. The influence of treatments upon light penetration, seedling stands, and yield was determined in the seeding year. In subsequent years, the effects of treatments upon stands, survival, yields and botanical composition of mixtures were determined.

The experiment was conducted as a factorial in a split-plot-randomized-block design with 3 replications. Main plots were comprised of the factorialized harvest management and companion crop treatments. Subplots were comprised of the factorialized nitrogen, phosphorus and species treatments. Each subplot was 5 by 30 feet, with two rows of crested wheatgrass seeded between adjacent plots. Treatments, and levels of each, were as follows:

Companion crop:

(1) None.

(2) Barley seeded in 6-inch rows (full seeding rate, 96 pounds per acre).

(3) Barley seeded in 18-inch rows (1/3 seeding rate, 32 pounds per acre).

Seeding year harvest management:

(1) Cut to simulate pasturing.

(2) Cut as grain or at the same time as grain.

Nitrogen levels:

(1) No nitrogen

(2) 40 pounds of nitrogen per acre applied as ammonium nitrate.

Phosphorus levels:

(1) No phosphorus

(2) 35 pounds of phosphorus per acre applied as treble-super phosphate.

Mixtures:

(1) Tana birdsfoot trefoil (Lotus corniculatus L.) seeded at 3.1 pounds per acre and Potomac orchardgrass (Dactylis glomerata L.) seeded at 2.8 pounds per acre in alternate rows. (Seeding rate was based on a pure live-seed index).

(2) Vernal alfalfa (Medicago sativa L.) seeded at 1.7 pounds per acre and Potomac orchardgrass seeded at 2.8 pounds per acre in alternate rows. (Seeding rate

was based on a pure live-seed index.)

Seedings were made in the spring of 1960 and 1961. Grass and legumes were seeded at a $\frac{1}{2}$-inch depth in alternate 6-inch rows in an east-west direction with a single-row cone-type seeder. Barley was seeded at right angles to the grass and legume rows in a north-south direction. Fertilizer was broadcast onto plots after seeding, using a machine which metered fertilizer from two Cole top-delivery hoppers. In 1960 redroot pigweed (*Amaranthus retroflexus*) and pigeon grass (*Setaria viridus*) were each broadcast on all plots at a rate of one pound per acre. Weed seed was not broatcast on 1961 plots, since these plots were heavily infested with wild oats (*Avena fatua* L.).

In the seeding year all plots were irrigated frequently to reduce moisture competition. Four 3-inch irrigations were sprinkler applied to 1960 seedings and five 3-inch irrigations to 1961 seedings. In years subsequent to seeding four to five 3-inch irrigations were applied to both 1960 and 1961 seedings.

Collection of Data

Percentage Occupancy - Beginning with the establishment year and continuing through subsequent years, the "percentage occupancy" of birdsfoot trefoil and alfalfa seedlings was measured on each plot in the spring and fall of each year. Measurements were made using a 36- by 1.8-inch frame subdivided into twenty 1.8- by 1.8-inch units. The frame was placed over a row of legume at 5 random locations within a plot to obtain a sample of 100 units. A unit was considered occupied by a species if all of its crown was included. The number of units occupied was expressed as percentage occupied or "percentage occupancy".

Light Measurements - The percentage of solar radiation above the barley companion crop which reached undersown legumes was measured by the technique of Bula *et al*. (5, p. 271-278). Using a measurement device patterned after the one described by Miller (30, p. 56-57), Bula *et al*. describe this device as follows:

> The device determines the ratio of the time average of two fluctuating quantities of light. Two vacuum photocells, suitably mounted to give the required angular and spectral responses, were supported on a rigid framework at a distance in front of the operator. One photocell remains above the oats and the other rests at a level of 3 inches above the soil in order to keep it free of dirt film. Carried by the operator with the batteries, the structure is pushed down a row while two electronic integrators add separately the responses of each cell. The integration is stopped after a fraction of a minute and the ratio of the two integrals in voltage is determined by a nullmeter-potentiometer combination. The average percentage transmission of the photosynthesizing radiation, incident on a given crop, which penetrates to the lower photocell is read directly from the potentiometer dial.

Considerable difficulty was experienced with this device in 1960 and successful readings were obtained on only one day. In 1961 readings were successfully made at 2-hour intervals from 6 a.m. to 6 p.m. on June 2, July 7, and July 26. At the latter date the companion crop was mature and its shading effect considered to be stabilized.

Yields - Yields of herbage were measured by clipping a 38-inch wide strip throughout the length of each plot. Each yield sample was weighed green and a sub-sample taken for moisture determination. Herbage yields were expressed in tons per acre at 12% moisture.

In the seeding year three harvests were made of the cut to simulate pasturing treatment. On the cut as grain or at the same time as grain treatment, yields of grain and of weeds, grass and legumes were measured.

Each year subsequent to the year of seeding, three harvests were taken. At each harvest the yield of legume and grass in mixtures was measured, in most cases, by harvesting twelve feet of adjacent grass and legume rows and hand separating. In some cases, where applicable, the constituent-differential method was used (9, p. 190-193).

RESULTS

Percentage Occupancy of Seedlings

1960 Seedings - The first measurements of percentage occupancy of legumes were made on June 16, 1960, prior to the initiation of harvest treatments. As a consequence, stand differences at this date reflect only species, fertilizer and companion crop effects. Alfalfa stands were significantly greater than those of birdsfoot trefoil. Stands of both species were not affected by fertilizer treatment but were significantly reduced, and to a like degree, with increasing levels of companion crop treatment (Table 2). In the fall of 1960 percentage occupancy of plants followed the same general pattern as in the spring. Once established, plants were able to withstand the competitive effect of barley and stands were not affected by harvest treatment.

Percentage occupancy readings in the spring of 1961 reflect the

Table 2. Percentage occupancy of alfalfa and birdsfoot trefoil plants in mixtures with orchardgrass in 1960, 1961 and 1962 as affected by companion crop treatments in 1960.*

Sampling date and species	1960 Companion crop treatments: No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	Ave.**
	%	%	%	%
June 14, 1960				
Alfalfa	49	46	34	43 a
Birdsfoot trefoil	45	40	32	39 b
Ave.**	47 a	43 b	33 c	
September 21, 1960				
Alfalfa	50	47	41	46 a
Birdsfoot trefoil	45	42	38	42 b
Ave.**	48 a	45 ab	40 b	
May 8, 1961				
Alfalfa	66	59	52	59 a
Birdsfoot trefoil	57	46	33	45 b
Ave.**	62 a	52 b	42 c	
October 10, 1961				
Alfalfa	67	64	57	62 a
Birdsfoot trefoil	69	55	46	57 b
Ave.**	68 a	60 b	51 c	
June 26, 1962				
Alfalfa	68	64	58	63 a
Birdsfoot trefoil	61	56	44	54 b
Ave.**	64 a	60 a	51 b	
September 10, 1962				
Alfalfa	66	62	57	62 a
Birdsfoot trefoil	64	54	46	55 b
Ave.**	65 a	58 ab	52 b	

* Means represent the average of 2 harvest management treatments, 4 fertilizer treatments and 3 replications.

** Average values for species or companion crop treatments within a sampling period not followed by the same letter are significantly different at the 5% level of probability (13, p. 1-42).

survival of plants throughout the winter and the influence of previous treatment upon survival (Table 2). In considering the data, one must bear in mind that occupancy reflects the degree of ground cover and not a fixed number of plants. Consequently, trends in occupancy can only be reliably compared between treatments within a given date, since the crowns of plants become larger between sampling dates and thus give higher readings. On this basis of comparison, stands of birdsfoot trefoil plants were affected more by previous treatment than those of alfalfa. The difference in percentage occupancy of alfalfa plants seeded without a companion crop and with a companion crop seeded in 6-inch rows was 14. In contrast, the difference in percentage occupancy of birdsfoot trefoil in those treatments was 24. The data indicate that more trefoil plants were lost during the winter than alfalfa plants. Occupancy readings in the fall of 1961 followed the same general trend as those in the spring (Table 2). Loss of plants did not occur during the growing season of 1961.

Percentage occupancy of alfalfa and birdsfoot trefoil plants in the spring and fall of 1962 followed the same trends as those in 1960 and 1961, with stands being reduced in proportion to the intensity of competition in the seeding year (Table 2).

<u>1961 Seedings</u> - Percentage occupancy of alfalfa and birdsfoot trefoil in 1961 was, in general, affected by companion crop treatments in a manner similar to that of 1960 seedings (Table 3). The data differed from that of 1960 as follows: (1) Stands of both species were equal, (2) percentage occupancy of birdsfoot trefoil was

Table 3. Percentage occupancy of alfalfa and birdsfoot trefoil plants in mixtures with orchardgrass in 1961 and 1962 as affected by companion crop treatments in 1961.*

Sampling date and species	1960 Companion crop treatments: No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	Ave.**
	%	%	%	%
August 17, 1961				
Alfalfa	52	48	41	47 a
Birdsfoot trefoil	55	51	36	47 a
Ave.**	54 a	50 a	38 b	
May 9, 1962				
Alfalfa	72	67	58	66 a
Birdsfoot trefoil	72	68	53	64 a
Ave.**	72 a	68 a	56 b	
September 11, 1962				
Alfalfa	62	60	51	58 a
Birdsfoot trefoil	66	57	51	58 a
Ave.**	64 a	58 a	51 a	

* Means represent the average of 2 harvest management treatments, 4 fertilizer treatments, and 2 replications.

** Average values for species or companion crop treatments within a sampling period not followed by the same letter are significantly different at the 5% level of probability (13, p. 1-42).

reduced by a companion crop to a greater degree than alfalfa in the seeding year, and (3) there was little evidence of loss of plants during the first winter. In considering the data from both seeding years, the following conclusions may be made: (1) Seedling loss occurred during the very early establishment period and the degree of loss was similar for both species, (2) fertilizer did not enhance the ability of seedlings to survive, (3) following the initial stand loss, further losses did not occur during the first year, (4) additional losses of birdsfoot trefoil stands occurred in one winter when plants were established with a companion crop, (5) with non-rhizomatous legumes, initial stand reductions caused by companion crops will be permanent.

Influence of a Barley Companion Crop on Herbage Yields in the Year of Seeding

The percentage occupancy values reported in the previous section reflect the influence of treatments on seedling loss. They do not, however, reflect the influence of treatments upon growth of surviving seedlings. In order to evaluate these effects, yields of herbage were measured on plots cut to simulate grazing and on plots harvested as grain or at the same time as grain. Since response to fertilizer was negative, discussion of yields are confined to the effects of companion crop treatments.

Yields When Cut to Simulate Pasturing - Yields of herbage at 3 harvests in 1960, as influenced by a companion crop, are shown in Table 4. At the first two harvests herbage was principally barley and weeds. Yields increased in proportion to density of barley plants

Table 4. Yields of herbage during the year of seeding, when cut as simulated pasture, as affected by companion crop treatments.*

Establishment year and harvest date	Companion crop treatments		
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows
	T./A.	T./A.	T./A.
1960			
June 28**	----	.66	.87
July 19	.35	.55	.80
September 1	1.18	.56	.18
Total	1.53	1.77	1.85
1961			
June 19	.37	.73	1.11
July 17	.94	.64	.34
September 14	.39	.36	.19
Total	1.70	1.64	1.73

* Averages of two legume species each seeded with orchardgrass under 4 levels of fertilization.

** Yields not measured from plots with no companion crop on June 28 since herbage was principally weeds.

and reflect the degree of competition in early season. At the last harvest barley and weeds had ceased growth and herbage was principally grass and legume. Yields of grasses and legumes at this harvest were inversely proportional to the earlier intensity of competition from the companion crop. Alfalfa-grass mixtures yielded .71 tons per acre and those of birdsfoot trefoil .56 tons per acre at the last harvest.

In 1961 yield trends were similar to those of 1960 at the first harvest (Table 4). Yields at the second harvest, however, were inversely proportional to the intensity of companion crop treatments. The difference in second harvest yield trends between years was due to the difference in the type of weed population. In both years the density of the weed population was inversely proportional to the intensity of competition from the companion crop. The weed population of redroot pigweed and pigeon grass in 1960, however, was suppressed by one clipping, whereas the weed population of wild oats in 1961 was not. Wild oats produced more herbage than barley after the first harvest, which resulted in greater yields.

At the last harvest in 1961, as in 1960, herbage harvested was principally grass and legume. In contrast to 1960, yields were not different on the non-companion crop and barley seeded in 18-inch row treatments. Yields were less, however, when herbage was grown with barley seeded in 6-inch rows. The data again reflect the adverse effect of a companion crop in the early establishment period of legumes.

Height of legumes was measured three weeks after the second harvest in 1960. Companion crop treatments had a marked effect on the regrowth of both species (Table 5). Regrowth of species seeded with barley in 6-inch rows was less than half that of species seeded without a companion crop. The data indicate the weakened condition in which seedlings established with a companion crop go into the overwintering period. Measurements of regrowth were not made after the second harvest of legumes seeded in 1961.

Yields of Weeds, Grass and Legumes at Grain Harvest - The barley companion crop decreased the yields of weeds, grass and legumes at grain harvest in 1960 (Table 6). Competition from weeds was much greater in the absence of barley, but was not as adverse to the growth of seedlings as the barley itself. The weed component was predominantly redroot pigweed and pigeon grass.

Yields of the weed component of herbage at the grain harvest in 1961 were 2.31, .45 and .10 tons per acre, respectively, for companion crop treatments of none, barley seeded in 18-inch rows, and barley seeded in 6-inch rows. Weed production, which was predominantly wild oats, was approximately twice that of 1960. Growth of grass and legume seedlings in 1961 was not enough to warrant measurement under companion crop treatments. Under the non-companion crop treatment each of these components yielded .02 tons per acre. This value is in sharp contrast to the approximately one-half ton of grass and legume herbage produced under the same treatment in 1960 and reflects the greater competition from wild oats than from redroot pigweed and pigeon grass.

Light Interception by the Barley Companion Crop

The percentages of solar radiation above the growing crop which

Table 5. Regrowth of alfalfa and birdsfoot trefoil plants, seeded in 1960, three weeks after the second simulated pasture harvest.

Legume species	1960 Companion crop treatments			Ave.
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	
	Inches	Inches	Inches	Inches
Alfalfa	11.5	9.7	4.6	8.6
Birdsfoot trefoil	9.6	6.9	3.8	6.8
Ave.	10.6	8.3	4.2	

Table 6. Yields of weeds and of grass and legume components of mixtures established under 3 companion crop treatments at grain harvest.

Companion crop treatment	Species group			Total
	Weeds	Legumes	Grass	
	T./A.	T./A.	T./A.	T./A.
None	1.29	.49	.46	2.24
Barley seeded in 18-inch rows	.11	.02	.04	.17
Barley seeded in 6-inch rows*	----	----	----	----

* Growth of weeds, grass or legumes grown with barley seeded in 6-inch rows was not enough to measure.

penetrated to legume seedlings during the days of June 21, July 7 and July 27 of 1961, are shown in Figures 1, 2 and 3.

On June 21 barley in 6-inch rows excluded the most light, followed by barley seeded in 18-inch rows (Figure 1). The non-companion crop plots were heavily infested with wild oats. At this early date, however, the wild oats had not made as much growth as barley and were less detrimental with respect to shading of seedlings.

On July 7 light interception data followed the same general trend as that of the previous sampling period (Figure 2). Differences due to treatment were smaller and the shading effect of wild oats was more pronounced during the morning and afternoon, due to its increased growth.

On July 26 wild oats on non-companion crop plots had a greater shading effect than either of the barley companion crop treatments, which had nearly equal effects (Figure 3). The increased shading was due to the greater height of wild oats in comparison with barley. Wild oats and barley were both mature on July 26.

Yields of Mixtures in Years Subsequent to Seeding

Yields of Mixtures in 1961 - In the presentation of percentage occupancy and yield measurements in the year of seeding, it was shown that competition from barley resulted in (1) death of some seedlings and (2) reduced growth of surviving seedlings. The death of seedlings occurred as a result of companion crop competition early in the season and was not affected by harvest management. Growth inhibition, however, was modified by harvest management and was greater when barley

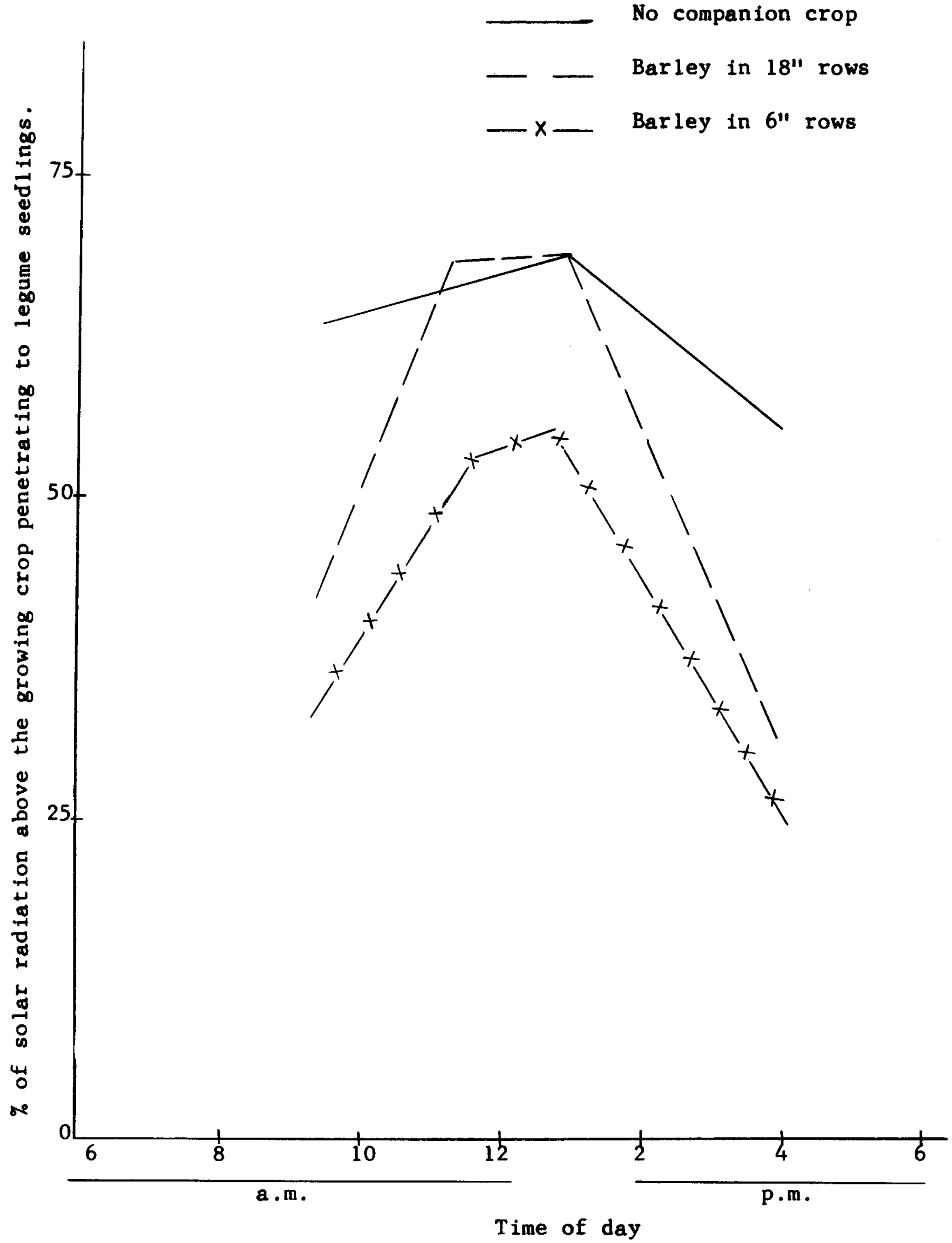

Figure 1. The % of solar radiation above the crop which penetrated to legume seedlings on June 21, 1961.

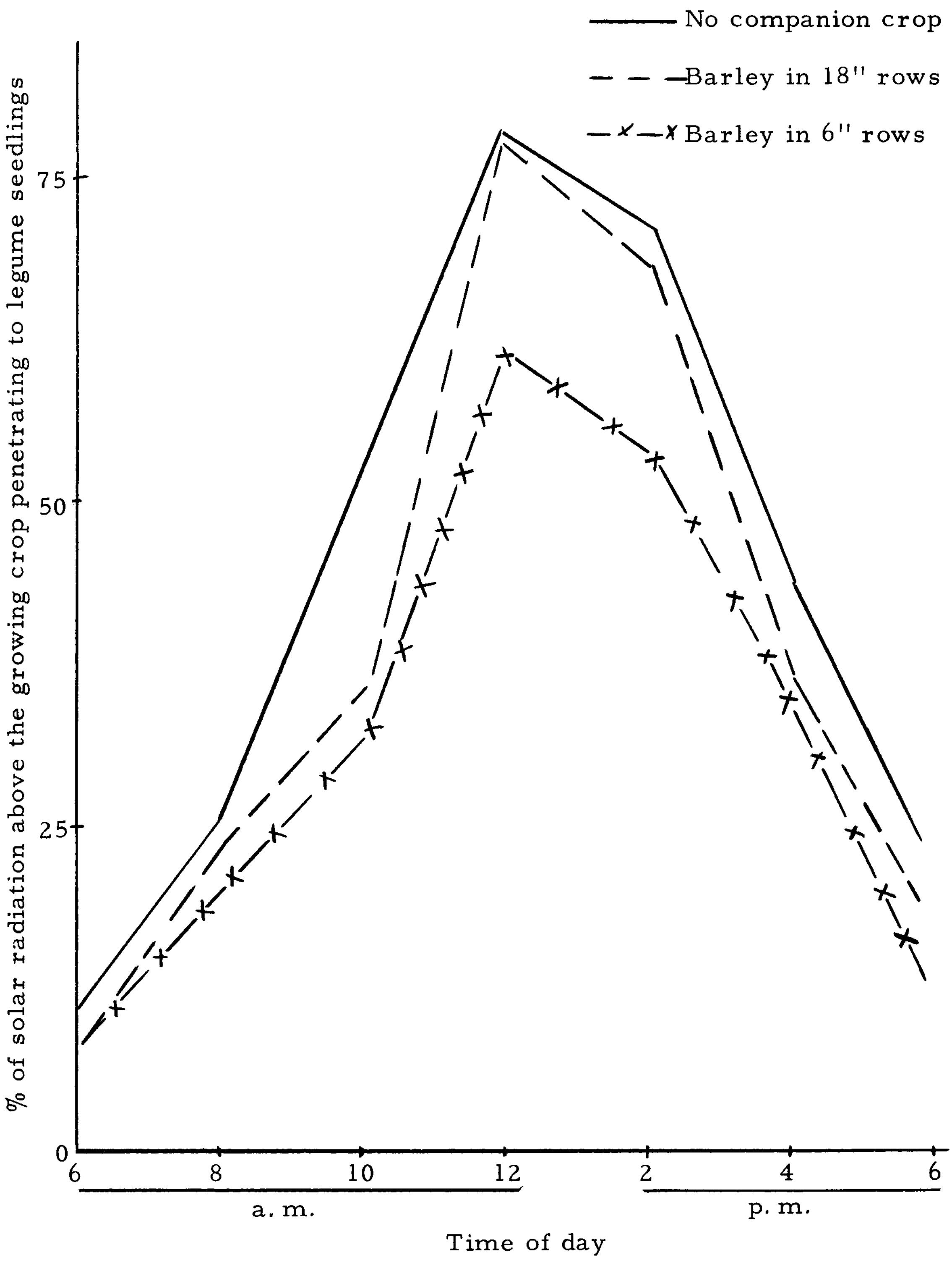

Figure 2. The percentage of solar radiation above the growing crop which penetrated to legume seedlings on July 7, 1961.

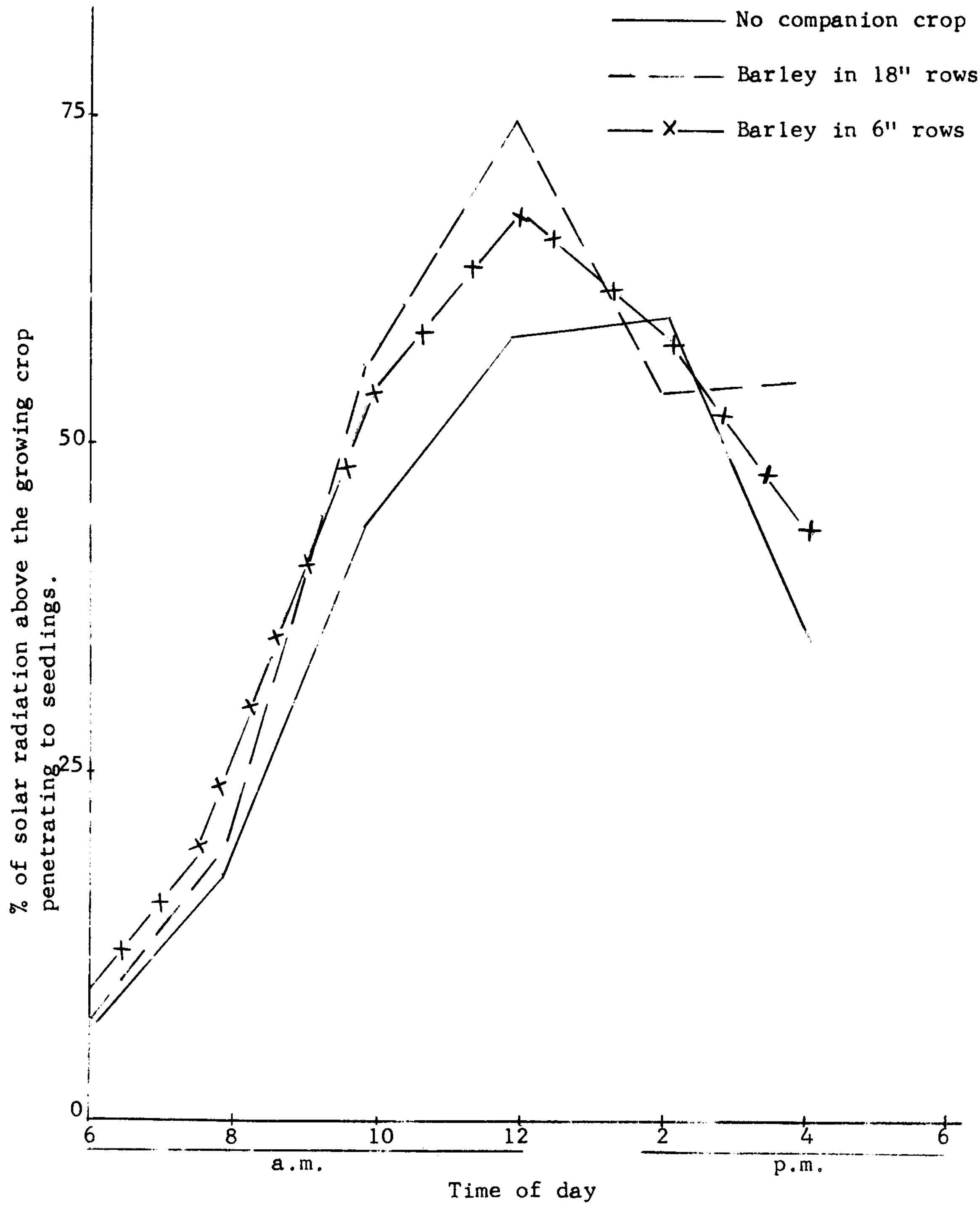

Figure 3. The percentage of solar radiation above the growing crop which penetrated to legume seedlings on July 26, 1961.

was matured to grain than when cut to simulate pasturing. In the following presentation, yield data will be discussed in terms of the effects of both stand reductions and inhibited growth of seedlings upon subsequent performance of mixtures and of grass and legume components.

The influence of companion crops on yields of mixtures in the year after seeding is shown in Table 7. At the first harvest yields decreased in proportion to the intensity of previous competition. The decrease may be attributed to both decreases in stand density and growth inhibition of seedlings in the previous year. Yields were greatest when barley had been previously cut as pasture. On the non-companion crop treatment, however, yields were greater when weeds were left standing until grain harvest than when they were cut frequently.

At the second harvest in 1961 yields of mixtures were not influenced by previous companion crop treatment when barley had been clipped periodically (Table 7).

When barley had been matured to grain, however, mixture yields decreased in proportion to previous competition. At the third harvest in 1961 yields were not affected by either previous companion crops or harvest management practice (Table 7).

Total season yield reductions, in 1961, of birdsfoot trefoil-grass mixtures established with barley seeded in 18- and 6-inch rows in 1960, were .21 and .76 tons per acre, respectively, when the barley had been cut as pasture and 1.14 and 1.32 tons per acre, respectively, when the barley had been harvested as grain. Yield reductions of alfalfa-grass mixtures for the same companion crop treatments were .05 and .36 tons per acre, respectively, when barley was cut as

Table 7. Yields* of birdsfoot trefoil-orchardgrass and alfalfa-orchardgrass mixtures in 1961 as affected by companion crop and harvest management treatments in 1960 (the year of establishment).

Harvest date, mixtures, and previous cutting treatment	1960 Companion crop treatments			
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	Ave.
	T./A.	T./A.	T./A.	T./A.
June 13, 1961				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	1.71 a	1.56 a	1.07 b	1.45 b
Cut as grain, 1960	1.81 a	.98 b	.83 b	1.21 c
Alfalfa-grass				
Cut as pasture, 1960	2.13 b	2.06 b	1.70 c	1.96 a
Cut as grain, 1960	2.42 a	1.70 c	1.32 d	1.81 a
July 18, 1961				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	.78 ab	.80 ab	.70 b	.76 b
Cut as grain, 1960	.89 a	.58 c	.53 c	.67 c
Alfalfa-grass				
Cut as pasture, 1960	1.20 b	1.25 b	1.21 b	1.22 a
Cut as grain, 1960	1.41 a	1.24 b	1.00 c	1.22 a
September 6, 1961				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	.85 a	.77 a	.81 a	.81 b
Cut as grain, 1960	.91 a	.91 a	.93 a	.92 b
Alfalfa-grass				
Cut as pasture, 1960	1.56 a	1.53 a	1.62 a	1.57 a
Cut as grain, 1960	1.76 a	1.68 a	1.54 a	1.66 a
Total yields 1961				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	3.34	3.13	2.58	3.02
Cut as grain, 1960	3.61	2.47	2.29	2.79
Alfalfa-grass				
Cut as pasture, 1960	4.89	4.84	4.53	4.75
Cut as grain, 1960	5.59	4.62	3.86	4.69

* Yield values for treatments within a mixture at a given harvest date or for harvest management treatment averages within a harvest date not followed by letters in common are significantly different at the 5% level of probability (13, p. 1-42).

pasture and .97 and 1.73 tons per acre, respectively, when barley had been harvested as grain.

Yields of Mixtures in 1962 (1960 Seedings) - Average yields of mixtures seeded in 1960 tended to increase in proportion to intensity of seeding-year companion crop treatment at the first harvest in 1962 (Table 8). It will be subsequently shown that this increase was due to increased yields of the grass component and not due to increased yields of legume.

At the second and third harvests in 1962, yields were reduced slightly, although not significantly, as a result of previous companion crop treatments (Table 8).

Yields of Mixtures in 1962 (1961 Seedings) - Seeding year harvest management practice in 1961 had little effect on 1962 yields of mixtures. Companion crop treatments of 1961 significantly reduced yields only at the first harvest in 1962 (Table 9). Later harvests, however, continued to show an apparent decrease in yield in proportion to the degree of previous competition from the companion crop. Yields of alfalfa-grass and birdsfoot trefoil-grass mixtures, established with barley seeded in 6-inch rows in 1961, were reduced .74 and .63 tons per acre, respectively, in 1962. These yield reductions were not as striking as those which occurred with mixtures seeded in 1960. The 1961 seeding was heavily infested with wild oats which was strongly competitive with seedlings on non-companion crop treatments.

Yields of Grass and Legume Components of Mixtures

Yields of mixtures reported in the previous section show only

Table 8. Yields* of birdsfoot trefoil-orchardgrass and alfalfa-orchardgrass mixtures in 1962 as affected by companion crop and harvest management treatments in 1960 (the year of establishment).

Harvest date, mixtures, and previous cutting treatment	1960 Companion crop treatments: No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	Ave.
	T./A.	T./A.	T./A.	T./A.
June 15, 1962				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	1.19 b	1.25 ab	1.31 ab	1.25 c
Cut as grain, 1960	1.39 ab	1.43 a	1.69 a	1.50 b
Alfalfa-grass				
Cut as pasture, 1960	1.62 b	1.79 ab	1.88 a	1.76 a
Cut as grain, 1960	1.81 ab	1.73 ab	1.71 ab	1.75 a
July 17, 1962				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	.36 a	.34 a	.32 a	.34 b
Cut as grain, 1960	.38 a	.32 a	.25 a	.32 b
Alfalfa-grass				
Cut as pasture, 1960	.97 a	.97 a	.88 a	.94 a
Cut as grain, 1960	1.04 a	.95 a	.83 a	.94 a
August 28, 1962				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	.46 a	.43 a	.40 a	.43 b
Cut as grain, 1960	.53 a	.41 a	.33 a	.42 b
Alfalfa-grass				
Cut as pasture, 1960	1.03 a	1.01 a	.94 a	.99 a
Cut as grain, 1960	1.06 a	.96 a	.91 a	.98 a
Total yields 1962				
Birdsfoot trefoil-grass				
Cut as pasture, 1960	2.01	2.02	2.03	2.02
Cut as grain, 1960	2.30	2.16	2.27	2.24
Alfalfa-grass				
Cut as pasture, 1960	3.62	3.77	3.70	3.70
Cut as grain, 1960	3.91	3.64	3.45	3.67

* Yield values for treatments within a mixture at a given harvest date or for harvest management treatment averages within a harvest date not followed by letters in common are significantly different at the 5% level of probability (13, p. 1-42).

Table 9. Yields* of birdsfoot trefoil-grass and alfalfa-grass mixtures in 1962 as affected by companion crop treatments in 1961.

Harvest date and mixture	1961 Companion crop treatments: No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	Ave.
	T./A	T./A.	T./A.	T./A.
June 20, 1962				
Birdsfoot trefoil-grass	1.39 a	1.03 b	.88 c	1.10 b
Alfalfa-grass	1.94 a	1.59 b	1.41 c	1.65 a
Ave.	1.67 a	1.31 b	1.14 c	
August 3, 1962				
Birdsfoot trefoil-grass	.68 a	.60 a	.58 a	.62 b
Alfalfa-grass	1.17 a	1.16 a	1.02 a	1.12 a
Ave.	.93 a	.88 a	.80 a	
September 9, 1962				
Birdsfoot trefoil-grass	.17 a	.17 a	.15 a	.16 b
Alfalfa-grass	.39 a	.35 a	.33 a	.36 a
Ave.	.28 a	.26 a	.24 a	
Total yield				
Birdsfoot trefoil-grass	2.24	1.80	1.61	1.88
Alfalfa-grass	3.50	3.10	2.76	3.12
Ave.	2.88	2.45	2.18	

* Yields of a mixture within a harvest or average yields of mixtures or companion crop treatments within a harvest not followed by letters in common are significantly different at the 5% level of probability (13, p. 1-42).

the quantitative effects of establishment practices. In grass-legume mixtures, however, the relationship of one species to another is of utmost importance. Maintenance of a legume in mixtures at a desired level is necessary both from the standpoint of its effect on quality of herbage and upon the growth of its grass associate. In the subsequent discussion the effects of treatment upon yield and interrelationship of grass and legume components will be considered.

Yields of grass and legume components of mixtures in 1961 and 1962, as affected by seeding year establishment practice in 1960, are presented in Tables 10 and 11. Yields of both grass and legume components were markedly decreased at the first harvest in 1961 as a result of previous companion crop treatment (Table 10).

At the second harvest, yields of components were not affected by previous companion crop treatment on plots previously cut as pasture. On those plots previously cut as grain, yields of legume components were adversely affected by previous companion crop treatment. Lower yields of legume were accompanied by slightly increased yields of grass. This compensating effect was more pronounced at the third harvest in 1961.

During all of 1961, grass yields were not particularly favored by association with one legume more than another. It would thus appear that in the first production year competitive effects of legumes with grass are not apparent until late season and that benefits of legumes with respect to nitrogen release were negligible.

At the first harvest in 1962 (Table 11) yields of the legume component were least on plots previously established with barley grown

Table 10. Yield of grass and legume components of birdsfoot trefoil-grass and alfalfa-grass mixtures at three harvests in 1961 as affected by seeding year treatments in 1960 and by associated species.

Harvest date, mixture and yield component	1960 Seeding year treatments					
	Cut as pasture			Cut as grain*		
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows
	T./A.	T./A.	T./A.	T./A.	T./A.	T./A.
June 13, 1961						
Birdsfoot trefoil-grass						
Legume	.44	.42	.23	.42	.17	.06
Grass	1.27	1.14	.84	1.39	.81	.77
Total	1.71	1.56	1.07	1.81	.98	.83
Alfalfa-grass						
Legume	1.08	1.13	.92	1.13	.85	.44
Grass	1.05	.93	.78	1.29	.85	.88
Total	2.13	2.06	1.70	2.42	1.70	1.32
July 18, 1961						
Birdsfoot trefoil-grass						
Legume	.47	.42	.40	.64	.31	.17
Grass	.31	.38	.30	.25	.27	.36
Total	.78	.80	.70	.89	.58	.53
Alfalfa-grass						
Legume	.92	.98	.90	1.08	.83	.62
Grass	.28	.27	.31	.32	.41	.38
Total	1.20	1.25	1.21	1.40	1.24	1.00
September 6, 1961						
Birdsfoot trefoil-grass						
Legume	.48	.32	.38	.50	.44	.28
Grass	.37	.45	.43	.41	.47	.65
Total	.85	.77	.81	.91	.91	.93
Alfalfa-grass						
Legume	1.17	1.19	1.26	1.42	1.28	.97
Grass	.39	.34	.36	.34	.40	.57
Total	1.56	1.53	1.62	1.76	1.68	1.54

* No companion crop treatments cut at the same time as grain harvest.

Table 11. Yields of grass and legume components of birdsfoot trefoil-grass and alfalfa-grass mixtures at three harvests in 1962 as affected by seeding year treatments in 1960 and by associated species.

Harvest date, mixture and yield component	1960 Seeding year treatments					
	Cut as pasture			Cut as grain*		
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows
	T./A.	T./A.	T./A.	T./A.	T./A.	T./A.
June 15, 1962						
Birdsfoot trefoil-grass						
Legume	.36	.26	.43	.64	.34	.42
Grass	.83	.99	.88	.75	1.09	1.27
Total	1.19	1.25	1.31	1.39	1.43	1.69
Alfalfa-grass						
Legume	1.31	1.40	1.44	1.44	1.41	1.09
Grass	.31	.39	.44	.37	.32	.62
Total	1.62	1.79	1.88	1.81	1.73	1.71
July 17, 1962						
Birdsfoot trefoil-grass						
Legume	.15	.12	.12	.24	.12	.06
Grass	.21	.22	.20	.14	.20	.19
Total	.36	.34	.32	.38	.32	.25
Alfalfa-grass						
Legume	.46	.49	.44	.52	.48	.39
Grass	.51	.48	.44	.52	.48	.44
Total	.97	.97	.88	1.04	.96	.83
August 28, 1962						
Birdsfoot trefoil-grass						
Legume	.22	.22	.20	.33	.25	.16
Grass	.24	.21	.20	.20	.16	.17
Total	.46	.43	.40	.53	.41	.33
Alfalfa-grass						
Legume	.76	.71	.66	.73	.67	.59
Grass	.27	.30	.28	.33	.29	.32
Total	1.03	1.01	.94	1.06	.96	.91

* No companion crop treatments cut at the same time as grain harvest.

to maturity. The decreased legume yields, however, were offset by increased grass yields. Grass grown in association with birdsfoot trefoil yielded twice as much as that grown with alfalfa. The increase in growth seems to be directly related to the amount of competition as manifested by the yield of legume associate. During the spring growth period there was evidently no benefit to grass from the associated legume.

At subsequent harvests in 1962 there is less evidence of a compensating effect in yields of mixture components. Yields of the legume component continued to be adversely affected by the barley crop grown to maturity in 1960. Decreased yields of legume, however, did not seem to be accompanied by increased yields of grass. The reason for this may be that in the latter part of the season nodule-nitrogen is being released to the grass. This beneficial effect should be in proportion to the amount of legume. Further evidence of this effect is apparent in that yields of grass grown with alfalfa at the latter harvests were almost twice those grown with birdsfoot trefoil. This was true even though competition in terms of legume yield should have been much greater in alfalfa-grass plots.

Yields of grass and legume components of mixtures in 1962, as affected by companion crop treatments in 1961, are presented in Table 12. As in the 1960 seedings, the barley companion crop reduced legume yields in the year after seeding, particularly when legumes had been seeded with barley grown to maturity. Yields of grass were reduced by previous companion crop treatment at the first harvest but showed little effect of previous treatment at the second harvest.

Table 12. Yields of grass and legume components of birdsfoot trefoil-grass and alfalfa-grass mixtures at three harvests in 1962 as affected by seeding year treatments in 1961 and by associated species.

Harvest date, mixture and yield component	1961 Seeding year treatments					
	Cut as pasture			Cut as grain*		
	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows	No companion crop	Barley in 18-inch rows	Barley in 6-inch rows
	T./A.	T./A.	T./A.	T./A.	T./A.	T./A.
June 20, 1962						
Birdsfoot trefoil-grass						
Legume	.37	.38	.24	.28	.23	.20
Grass	.98	.62	.76	1.16	.84	.56
Total	1.35	1.00	1.00	1.44	1.07	.76
Alfalfa-grass						
Legume	1.18	1.10	.98	1.25	.93	.71
Grass	.58	.52	.61	.86	.63	.54
Total	1.76	1.62	1.59	2.11	1.56	1.25
August 3, 1962						
Birdsfoot trefoil-grass						
Legume	.42	.37	.36	.45	.35	.22
Grass	.23	.22	.24	.26	.27	.34
Total	.65	.59	.60	.71	.62	.56
Alfalfa-grass						
Legume	.83	.96	.84	.96	.82	.60
Grass	.28	.28	.29	.28	.26	.31
Total	1.11	1.24	1.13	1.24	1.08	.91

* No companion crop treatments cut at the same time as grain harvest.

DISCUSSION

In considering the data presented, results will be discussed in terms of objectives set forth in Aim and Scope. The loss of seedlings which occurred in this experiment was similar to those reported by other investigators (21, p. 627-630) (40, p. 442-444). Data from this experiment, however, delineated the period of seedling loss to within a few weeks after emergence. Since stand losses were not affected by fertilizer treatments and since moisture was not limiting during this period, it may be assumed that barley was not competing for nutrients or moisture.

The adverse effects of a companion crop during this period would thus seem to be due to its influence on soil temperature and light intensity. Barley grows very rapidly in comparison to legume seedlings. Cooper and Ferguson (8, In press) have reported barley to be 10 inches high when legume seedlings were less than 2 inches high. Three weeks later barley had attained a height of 29 inches. From their data it is apparent that light intensity and temperature in the micro-environment is modified very early in the establishment period. Reduced light intensity under barley was recorded five weeks after seeding in this experiment and soil temperatures have been shown to be 3 to 8^{o}F. less under a barley companion crop (8, In press).

Although the data presented show that barley excluded a large proportion of light, seedlings received 25% or more of the incident light each day. At noon values ranged from 60 to 70%. Under Montana conditions, light intensity may vary from 5,000 f.c. in early morning to more than 10,000 f.c. at high noon. With these values in mind, seedlings should have received 1,000 f.c. or more of light during most of each day, which should have been adequate for growth. Nevertheless, since plots were irrigated frequently and species did not respond to fertilization, all growth data point to light as a limiting factor.

During the cool springs of the Intermountain Region, temperature differences could be of particular importance. The warmer daytime temperature of the micro-environment of seedlings grown without a companion crop might favor photosynthesis. Likewise, cooler night temperatures should reduce respiration (37, p. 93-95). The relationship of these two factors might in turn affect the light compensation points of seedlings.

Following the first period of seedling loss, additional losses did not occur during the first year. Growth of surviving seedlings, however, was retarded and the degree of inhibition was not affected by fertilizer treatment or moisture. Growth retardation appeared to be mainly a result of reduced light intensity since modification of competition intensity by periodic clipping increased seedling growth. Clipping, however, appeared to be more detrimental to the growth of seedlings than the competition provided by unclipped redroot pigweed and pigeon grass.

Yields of legumes in years subsequent to seeding were reduced as a result of growth retardation during the establishment years. This effect was more pronounced and of longer duration when barley had been allowed to mature than when it was clipped frequently. Reduced yields of legumes were, in some cases, offset by increased yields of grass. The compensating effect of grass and legume yield has also been noted in grass-legume mixtures by Roberts and Olson (44, p. 695, 701).

Reductions in stands of legume in the seedling year persisted for the duration of the experiment and resulted in decreased forage production. Since both legumes were non-rhizomatous species, initial stand reductions may be expected to persist for the life of the stand. Yield reductions due to decreased stands have also been reported for red clover seeded with a companion crop (40, p. 442-444) (6, p. 385). Klebesadel and Smith, (21, p. 627-630), however, reported that reduced stands of alfalfa did not result in reduced yields. It would seem that the question of yield reductions from thinner stands is dependent upon whether or not stands were reduced below the density needed for optimum production. Slight reductions in stands may be compensated for by larger, more productive plants.

Grass growth was least in early season and most in late season when grown with alfalfa. The effects of legumes on grass are not too clear. Alfalfa should be more competitive than birdsfoot trefoil throughout the season. It began growth earlier and recovered more rapidly after clipping in this experiment. It is a taller-growing species and was much more productive than birdsfoot trefoil. The better spring growth of grass with birdsfoot trefoil would appear to be due to less competition. In late summer, however, this was not the case. The better grass production with alfalfa in late season might be due to greater nitrogen release by this species, or perhaps some shading in the hot days of mid-summer is advantageous to grass growth.

From the results presented, a number of areas of additional investigation could be selected. Since light and soil temperature appeared to be plausible causes influencing seedling growth, separate studies were initiated to investigate these factors.

SOIL TEMPERATURE STUDIES--THE INFLUENCE OF SOIL TEMPERATURE AND PHOSPHORUS LEVEL UPON GROWTH CORRELATIONS IN BIRDSFOOT TREFOIL AND ALFALFA AND UPON PHOSPHORUS AND NITROGEN UPTAKE

EXPERIMENTAL PROCEDURE

The experiment was conducted in two phases. In phase one Tana birdsfoot trefoil and Ranger alfalfa were each grown in the greenhouse under three soil temperatures and three phosphorus fertility levels. Soil temperatures were 12, 18 and 24°C. and phosphorus levels were 13.3, 26.6 and 40 pounds of P per acre. As only three temperature tanks were available, temperature levels were not replicated. Within each temperature level legume and phosphorus treatments were factorialized in a completely random design of two replicates. The design permitted the analysis of variance as follows:

Source of variance	DF
Temperature level (T)	2
Legumes (L)	1
Phosphorus levels (P)	2
P x T	4
P x L	2
T x L	2
T x L x P	4
Experimental error	18
Total	35

Preparation of Soil

Soil of the Hazelair series, obtained from the Camp Adair experimental area near Corvallis, Oregon, was used in the experiment. Hazelair soils occur at elevations of 200 to 500 feet in a climate having mean annual precipitation of 40 inches with dry, cool summers and cool, wet winters, an average minimum temperature of 41°F., an average maximum temperature of 63° F., and an average frost-free period of 200 days. Hazelair soils are mapped in foothill regions of Central Willamette Valley and are used principally for cereal grains and pasture. They are dark brown to dark grayish-brown in color. Throughout the profile the surface soil is silt loam to a depth of 14 inches, silty clay loam to a depth of 28 inches, and clay from 28 to 36 inches. The soil is underlain at 38 inches with hard fractured, horizontally bedded, fine-grained sandstone.

Soil used in the experiment was taken from the surface 6 inches. The soil, as taken from the field, had a pH of 5.2 and an organic content of 3.85%. Phosphorus and boron contents were 3 and 0.36 ppm. and K, Ca, and Mg contents were 0.86, 3.8, and 3.2 me., respectively. The soil was limed to pH 6.5 by adding 250 pounds of lime per acre and incubating for a period of six weeks. Following incubation, the soil was divided into three lots, mixed with an equal quantity of sand, and fertilized with treble-super phosphate at the prescribed rates.

Pots used in the experiment were made by removing the bottoms from two Number 10 cans and soldering the two cans to a third. Each pot was 7 inches in diameter and 21 inches deep. Each pot was filled with an equal weight of soil to within $1\frac{1}{2}$ inches of the top. Seed of the appropriate species was seeded at the rate of 10 seeds per pot. Following seeding, pots were placed on a greenhouse bench for a period of two weeks to allow germination and emergence under uniform conditions. During this period pots were watered daily. At the end of the two-week period, seedlings were reduced to three per pot and pots were placed at random in the water baths to which they had been assigned. Pots were held in position by a board cover in which holes had been cut to insert each pot. In order to minimize the influence of soil and water bath temperatures upon air temperatures, one inch of vermiculite was applied to the soil surface of each pot. In addition, a piece of plastic was fitted around each pot to cover the space between the pot and the edge of the hole in which it was inserted.

During the course of the experiment soil moisture was maintained near field capacity. Pots were weighed periodically and water added to bring each pot to a weight corresponding to that representing the soil at field capacity.

Air temperature was maintained at approximately 70°F. during the experimental period.

Natural lighting was supplemented by two XHO fluorescent tubes and two 40 watt incandescent bulbs suspended over each temperature tank at a height of 27 inches. Length of photoperiod was 16 hours during the experimental period. Plants received natural daylight plus 400 f.c. during the natural daylight period and 400 f.c. only during the extension photoperiod which corresponded to that time before sunrise and after sunset.

Data Collection

Yield - Following a growth period of 90 days, determined by beginning bloom of alfalfa, tops of all plants were harvested, separated into stem and leaf components, dried, and weighed. Roots were washed free of soil, dried, and weighed. The leaf and stem components from each pot were then combined and the tops and roots each ground for chemical analyses.

Leaf Area - From each sample of leaves, a subsample of 20 leaves was taken. The subsample was placed on light sensitive paper in a darkroom and exposed to light for 10 seconds. The green leaf sample was then dried and weighed. The light sensitive paper was developed, dried, and leaf outlines cut out and weighed. From the weight of paper leaf outlines and the weight of a given area of paper, the leaf area per sample was calculated. The $cm.^2$ of leaf area per gram of oven dry leaf subsample was then computed and this factor in turn multiplied by the total oven dry weight of leaves per pot.

Chemical analyses - Shoot and root samples were analysed for N and P content. Nitrogen content was determined by the Kjeldahl method. Phosphorus was determined colorimetrically by the method of Koenig and Johnson (22, p. 155-156).

Data Analyses - Yields of roots and tops, root-shoot ratios, leaf area and area-weight relationships were analysed by the analysis of variance.

The second phase of the experiment evaluated the influence of two temperature levels (12 and 24°C.) and three phosphorus levels (13.3, 26.6 and 40 pounds P per acre) upon root growth as measured by weekly root tracings. Tana birdsfoot trefoil and Ranger alfalfa were each grown in soil placed between two glass plates which were inclined at an angle. These plates were fitted into grooves of a specially constructed box which excluded light. One side of the box was readily removable to permit observation and tracing of root growth.

At weekly intervals a sheet of plastic was placed over the exposed glass plate and the visible root area traced with a wax pencil. The color of the pencil was changed each week to permit delineation of weekly growth increments.

Due to space limitations, it was not possible to replicate treatments in phase two. Each set of six boxes, representing treatments of each legume at each of three P levels, was placed in a specially constructed tank, which, in turn, was placed within its assigned temperature bath.

The soil used in phase two and its preparation was the same as that in phase one. Likewise, all management procedures, such as seeding and maintenance of light and irrigation regimes, were similar to those in phase one.

RESULTS

Yields of Roots and Tops, and Root-Top Ratios

Root growth of both species increased with increasing soil temperature (Table 13). The percentage increase in growth was greatest between 12 and 18^{o}C. At each soil temperature the growth of alfalfa roots was approximately double that of birdsfoot trefoil.

Top growth of alfalfa increased to about the same degree as roots with increasing temperature (Table 13). In contrast, top growth of birdsfoot trefoil was markedly stimulated with increasing soil

Table 13. The influence of soil temperature upon root growth, top growth, and root-top ratios of birdsfoot trefoil and alfalfa.

Species	Soil temperature 12°C. Roots	12°C. Tops	12°C. Root-top ratio	18°C. Roots	18°C. Top	18°C. Root-top ratio	24°C. Roots	24°C. Tops	24°C. Root-top ratio
	g.	g.		g.	g.		g.	g.	
Birdsfoot trefoil	.64	.50	1.27	1.25	2.60	.48	1.43	3.63	.39
Alfalfa	1.15	.92	1.27	2.38	2.35	1.10	3.28	2.84	1.16

L.S.D.'s for comparing differences among species at one level of temperature or among temperatures at one level of species:

Root growth	2.24
Top growth	.51
Root-top ratios	.29

temperature levels. Top growth of birdsfoot trefoil increased from .50 grams at 12°C. to 3.63 grams at 24°C., which represented a seven-fold increase. In contrast alfalfa tops increased from .92 grams at 12°C. to 2.84 grams at 24°C., which represented only a three-fold increase. At a soil temperature of 12°C., alfalfa produced a greater yield of tops than birdsfoot trefoil. At the higher temperatures, however, top yields of birdsfoot trefoil were greater than those of alfalfa.

Root-top ratios (root weight/top weight) of both species declined with increasing soil temperatures. The root-top ratio of birdsfoot trefoil decreased more markedly than that of alfalfa, due to greater stimulation of top than of root growth. At 12°C. root-top ratios of both species were equal. At higher temperatures the ratio of roots to tops was much lower for birdsfoot trefoil than for alfalfa.

Top growth of either species was not significantly affected by phosphorus level. Root growth of both species responded to phosphorus in a similar manner and was greater at 26.6 and 40 than at 13.3 pounds of P per acre (Table 14). Phosphorus was of more importance at low than at high temperatures, which is in agreement with other work (28, p. 109-113). The temperature by phosphorus interaction, however, was not significant. Root-top ratios were .79, 1.05 and .96 at phosphorus levels of 13.3, 26.6 and 40 pounds of P per acre, respectively.

<u>Leaf Area-Growth Relationships</u>

Since leaf area and weight measurements were made only at the end

Table 14. Average root yields of birdsfoot trefoil and alfalfa as influenced by phosphorus at three soil temperature levels.

Pounds P per acre	Soil temperature 12°C.	18°C.	24°C.	Ave.
	g.	g.	g.	g.
13.3	.55	1.41	2.24	1.40
26.6	.88	2.16	2.55	1.86
40.0	1.26	1.87	2.28	1.80
Ave.	.90	1.81	2.36	

of the experiment, calculations of net assimilation rates were not possible. The relationship of grams of dry matter to leaf area, however, does furnish an estimate of net assimilation and is presented in Table 15. Alfalfa produced a greater amount of dry weight per $cm.^2$ of leaf area than birdsfoot trefoil at all temperatures. The assimilation efficiency of both species declined with increasing temperature.

In considering these data, several factors should be taken into account. Birdsfoot trefoil in all treatments flowered several weeks earlier than alfalfa and both species flowered earlier with increasing temperature. The shift from vegetative to reproductive growth may have resulted in reduced assimilation efficiency. If this were the case, it would account for the difference in assimilation efficiency between species and among temperatures. The reduction in assimilation efficiency with increasing temperature may be due, in part, to self-shading of the larger plants obtained with higher soil temperatures. Self-shading could be of particular importance under the low winter light intensities of western Oregon.

Influence of Treatments Upon the P and N Content of Legumes

In order to obtain samples of adequate size for chemical analyses, herbage from both replications was composited. The limited number of samples precluded the use of statistical analyses and the interpretation of the phosphorus by temperature interaction.

The influence of temperature upon P and N content of herbage, averaged across all phosphorus levels, is shown in Table 16. Phosphorus content of tops of both species was highest at 24°C. There

Table 15. Assimilation efficiency of birdsfoot trefoil and alfalfa grown under three soil temperature levels.

Species	Soil temperature			Ave.
	12°C.	18°C.	24°C.	
	mg. dry wt./cm.^{2} leaf area*			
Birdsfoot trefoil	20.4	13.2	12.8	15.5
Alfalfa	26.3	20.1	20.8	22.4
Ave.	23.3	16.6	16.8	

* One side of leaf only.

Table 16. The influence of soil temperature upon the P and N content of tops and roots of birdsfoot trefoil and alfalfa.*

Species	Portion of plant analysed and soil temperature					
	Tops			Roots		
	12°C.	18°C.	24°C.	12°C.	18°C.	24°C.
	% phosphorus					
Birdsfoot trefoil	.11	.11	.15	.11	.13	.15
Alfalfa	.13	.11	.16	.12	.12	.08
Ave.	.12	.11	.16	.12	.12	.10
	% nitrogen					
Birdsfoot trefoil	3.4	2.8	3.4	2.2	2.2	2.4
Alfalfa	3.2	2.7	3.8	2.2	2.3	2.3
Ave.	3.3	2.8	3.6	2.2	2.2	2.4

* Each value is the average of samples grown under three phosphorus fertilization rates.

appeared to be little difference in phosphorus content at 12 and 18°C. Phosphorus content of roots of birdsfoot trefoil increased with increasing temperature, while that of alfalfa was similar at 12 and 18°C. and appeared to decline at 24°C. The low value at the latter temperature, however, may be a result of experimental error due to the small number of samples.

Nitrogen content of tops of both species was greater at 12 and 24°C. than at 18°C. (Table 16). The reason for the lower values at 18°C. is not known. The results, however, agree with those of Parks and Fisher (38, p. 257-259) who found the percentage of N in ryegrass to be lower when grown at a soil temperature of 20°C. than at 10 or 30°C. Nitrogen content of roots did not appear to be influenced greatly by soil temperature.

Phosphorus fertilizer increased the P content of tops of both species slightly (Table 17). Phosphorus content of roots did not show a consistent trend with respect to P fertilizer effects. Nitrogen content of tops did not appear to be affected by P applications, while that of roots was least at the higher P application rates.

Phosphorus and nitrogen uptake per plant of alfalfa and birdsfoot trefoil increased with increasing soil temperatures (Table 18). Phosphorus uptake by alfalfa was nearly twice that of birdsfoot trefoil when species were grown in soil maintained at 12°C. At 18°C. P uptake was slightly greater by alfalfa and at 24°C. slightly greater by birdsfoot trefoil. The latter effect may be a result of the unusually low phosphorus content obtained for alfalfa grown in a soil at 24°C. (Table 16).

Table 17. The influence of P fertilization upon the P and N content, on a dry weight basis, of birdsfoot trefoil and alfalfa.*

Species	Portion of plant analysed and pounds P applied					
	Tops			Roots		
	13.3	26.6	40.0	13.3	26.6	40.0
	% phosphorus					
Birdsfoot trefoil	.11	.13	.14	.14	.11	.14
Alfalfa	.12	.14	.14	.10	.10	.12
Ave.	.12	.14	.14	.12	.10	.13
	% nitrogen					
Birdsfoot trefoil	3.2	3.2	3.1	2.5	2.1	2.1
Alfalfa	3.2	3.3	3.3	2.5	2.2	2.1
Ave.	3.2	3.2	3.2	2.5	2.2	2.1

* Each value is the average of samples grown under three soil temperature levels: 12, 18 and 24°C.

Table 18. Average phosphorus and nitrogen uptake per plant of birdsfoot trefoil and alfalfa grown under three soil temperatures.

Portion of plant analysed	Alfalfa			Birdsfoot trefoil		
	12°C.	18°C.	24°C.	12°C.	18°C.	24°C.
	mg. P per plant					
Tops	.40	.86	1.51	.18	.95	1.81
Roots	.46	.95	.87	.26	.54	.71
Total	.86	1.81	2.38	.44	1.49	2.52
	mg. N per plant					
Tops	9.79	21.11	35.93	5.66	24.24	41.09
Roots	8.42	18.21	25.11	4.70	9.16	11.42
Total	18.21	39.32	61.04	10.36	33.30	52.51

Nitrogen uptake by both species also increased with temperature (Table 18). Since the N content of herbage was similar, the increased uptake is a reflection of the increased yield obtained with increasing temperature. Nitrogen uptake of alfalfa was greater than that of birdsfoot trefoil at all temperatures as were total yields.

Visual Root Growth

Root growth of alfalfa and birdsfoot trefoil with time, as affected by soil temperature and P fertilization, is shown in Figures 4 through 11.

Root growth of five-week old alfalfa plants increased markedly with increasing temperature (Figure 4). In contrast, root growth of five-week old birdsfoot trefoil seedlings appeared to be unaffected by soil temperatures (Figure 5). Root growth of both species, at a soil temperature of 12°C. appeared to be greatest at the medium rate of P fertilizer application (Figures 4 and 5).

At seven weeks of age, root growth of both species showed a marked response to temperature (Figures 6 and 7). Growth of alfalfa roots was greater than that of birdsfoot trefoil at both soil temperatures. Roots of both species continued to show the most favorable response to the medium rate of P fertilization at 12°C. At seven weeks roots of birdsfoot trefoil began to exhibit the characteristic branched tap root in contrast to the single tap root of alfalfa.

At nine weeks of age, alfalfa roots at 12°C. and birdsfoot trefoil at 24°C. had penetrated to the bottom of the observation boxes (Figures 8 and 9). Lateral root growth of both species was more

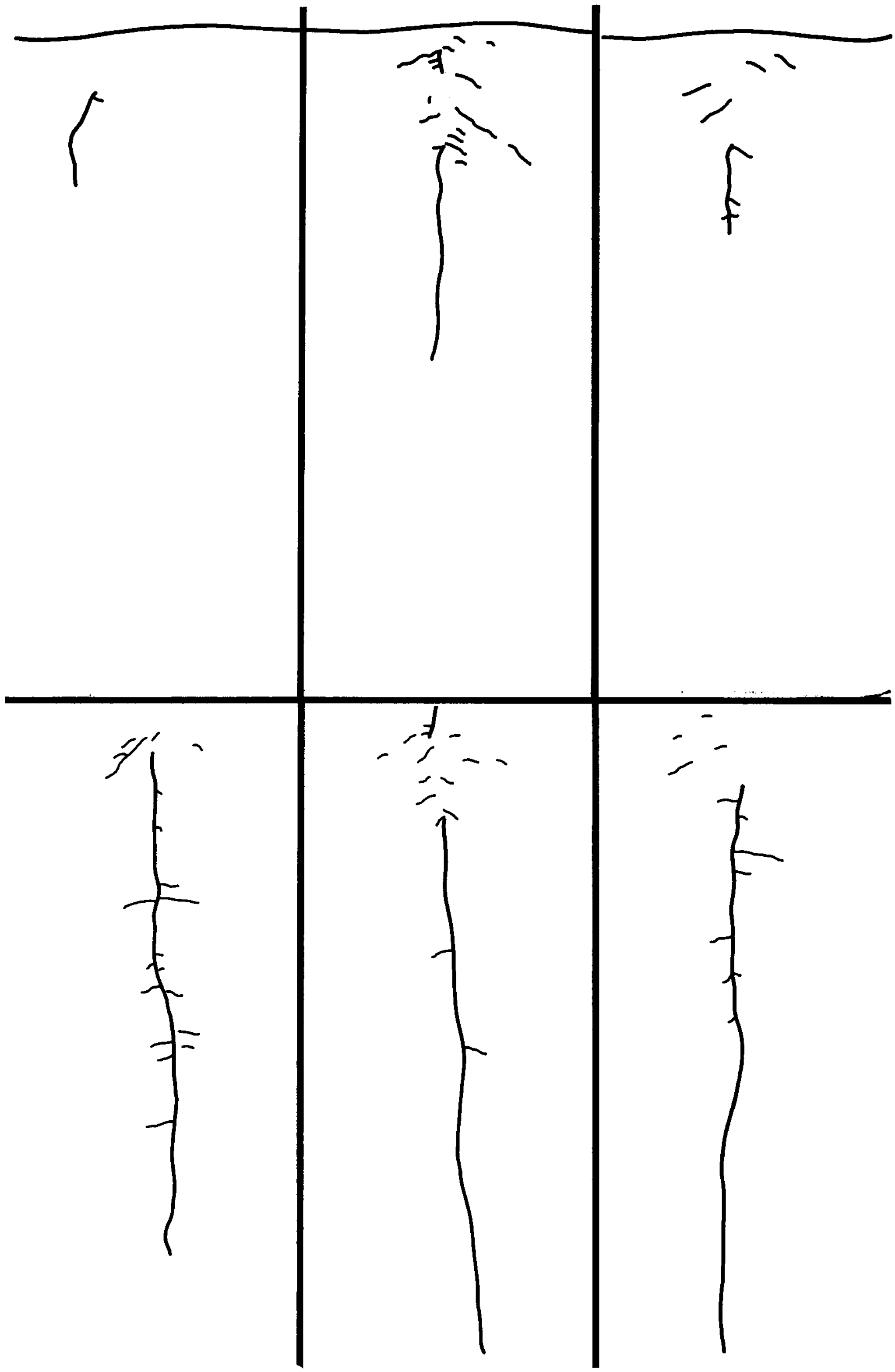

Figure 4. Root growth of 5-week old alfalfa seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

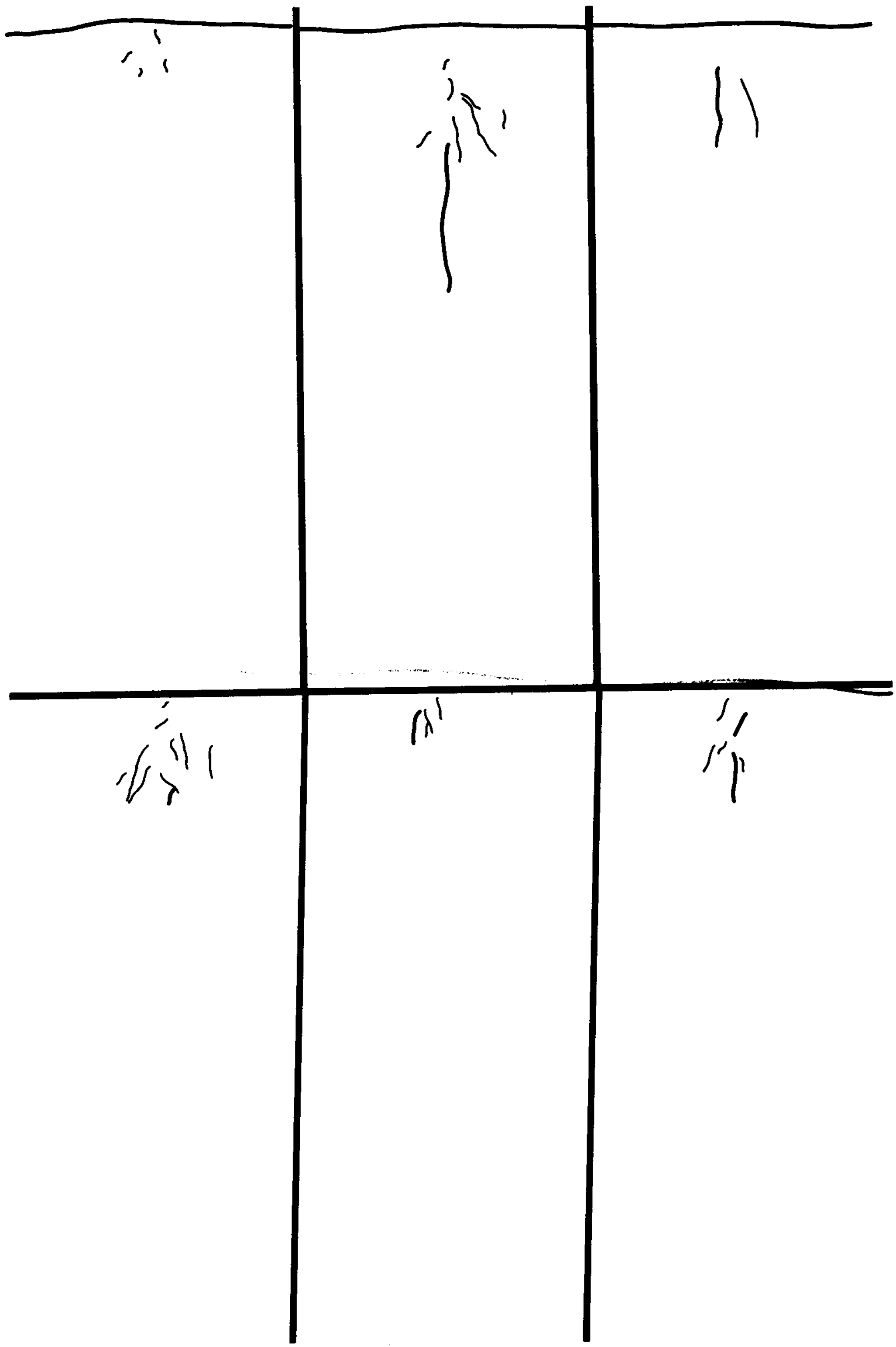

Figure 5. Root growth of 5-week old birdsfoot trefoil seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

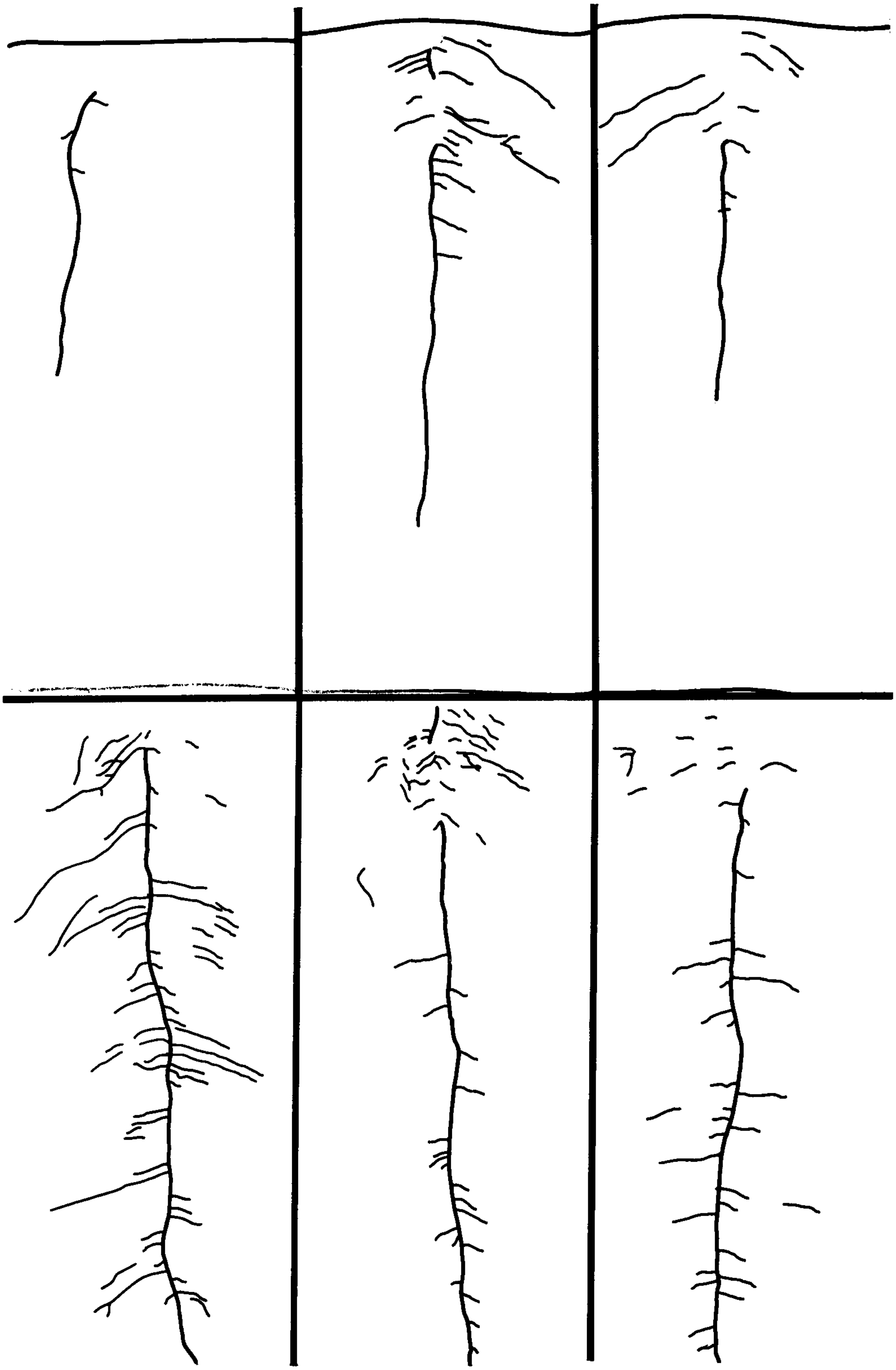

Figure 6. Root growth of 7-week old alfalfa seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

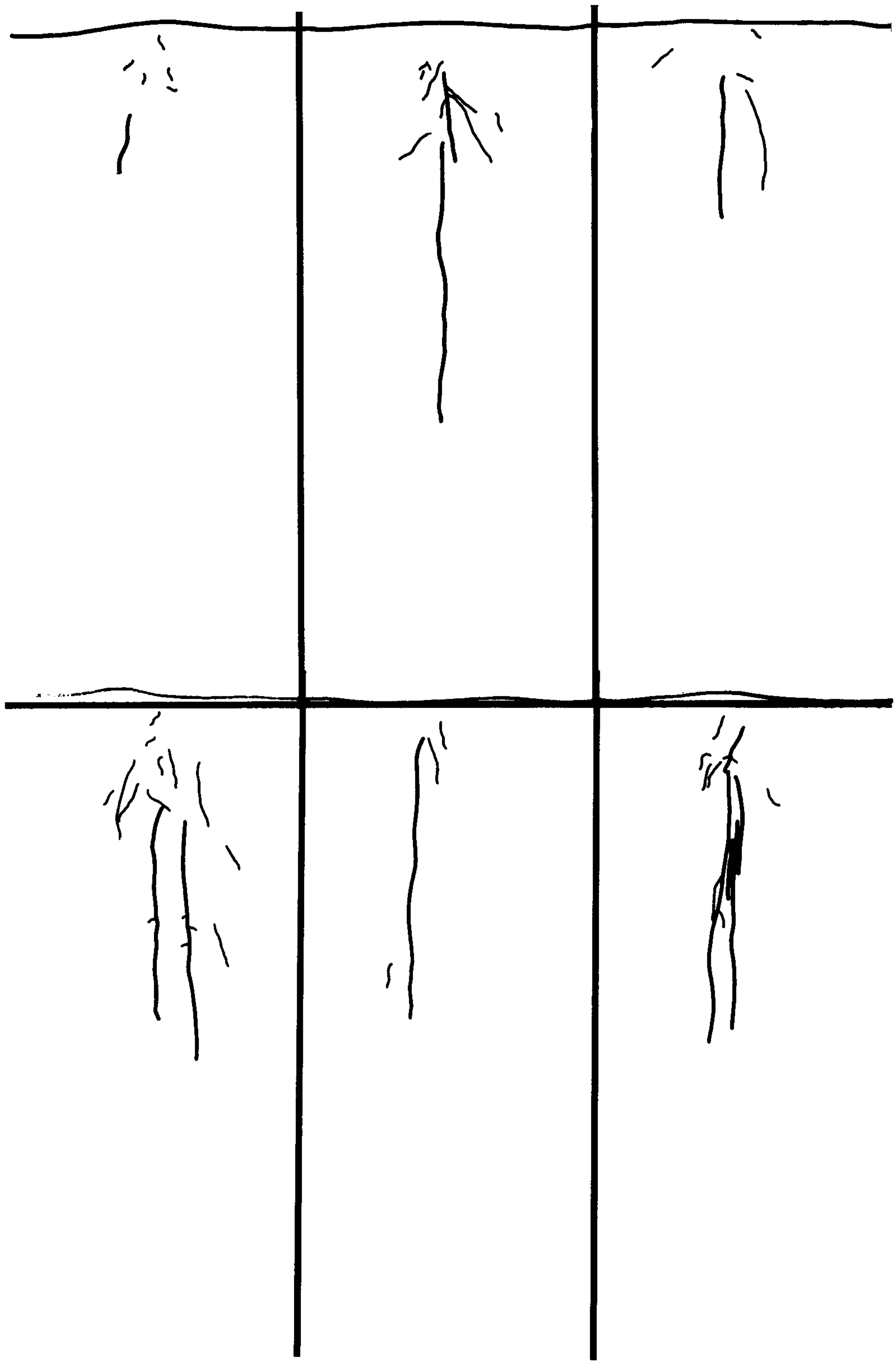

Figure 7. Root growth of 7-week old birdsfoot trefoil seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

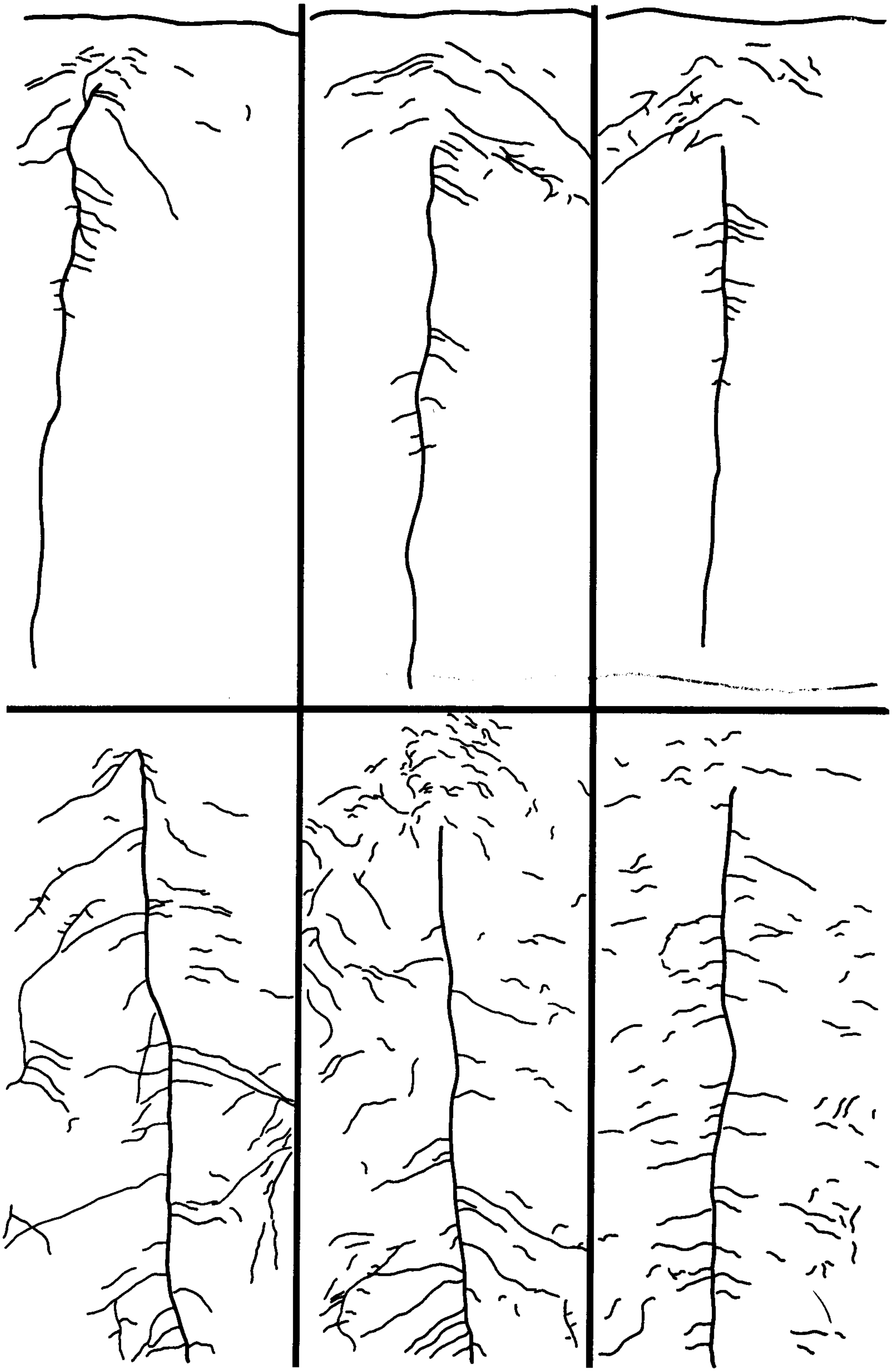

Figure 8. Root growth of 9-week old alfalfa seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

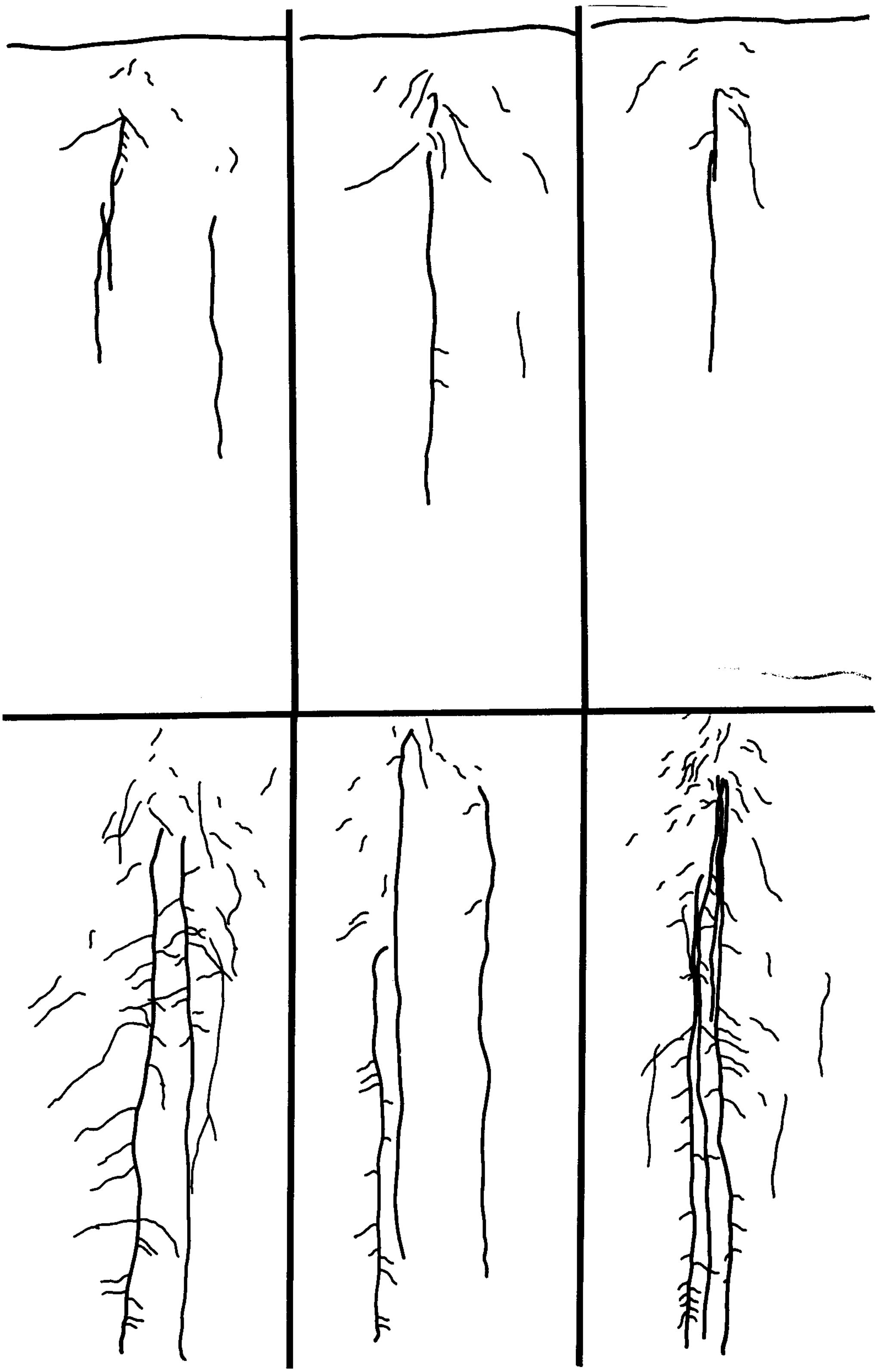

Figure 9. Root growth of 9-week old birdsfoot trefoil seedlings at soil temperatures of 12°C. (upper) and 24°C. (lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

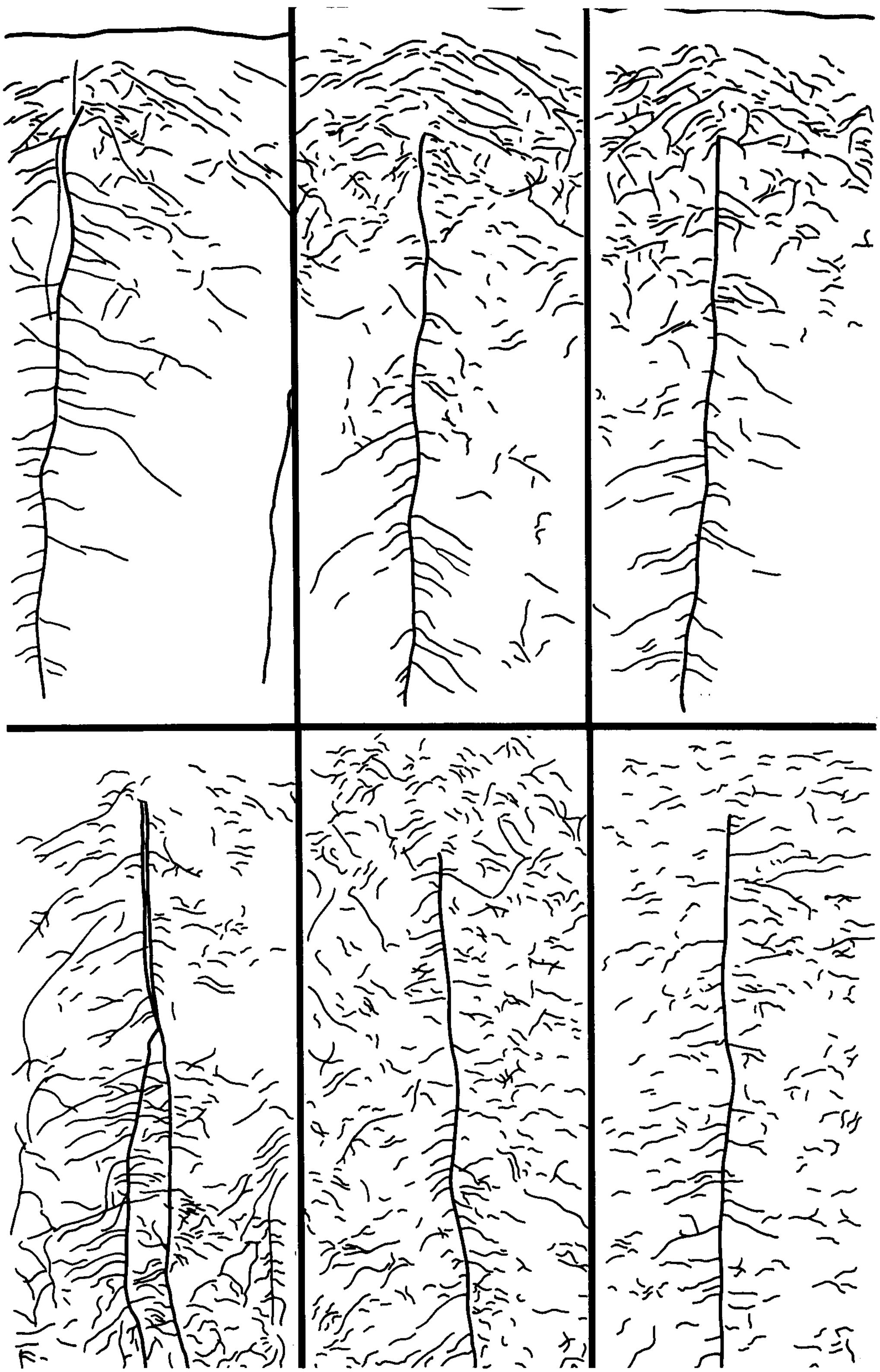

Figure 10. Root growth of alfalfa at flowering. Soil temperatures 12°C. and 24°C.; age 15 and 12 weeks (upper and lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

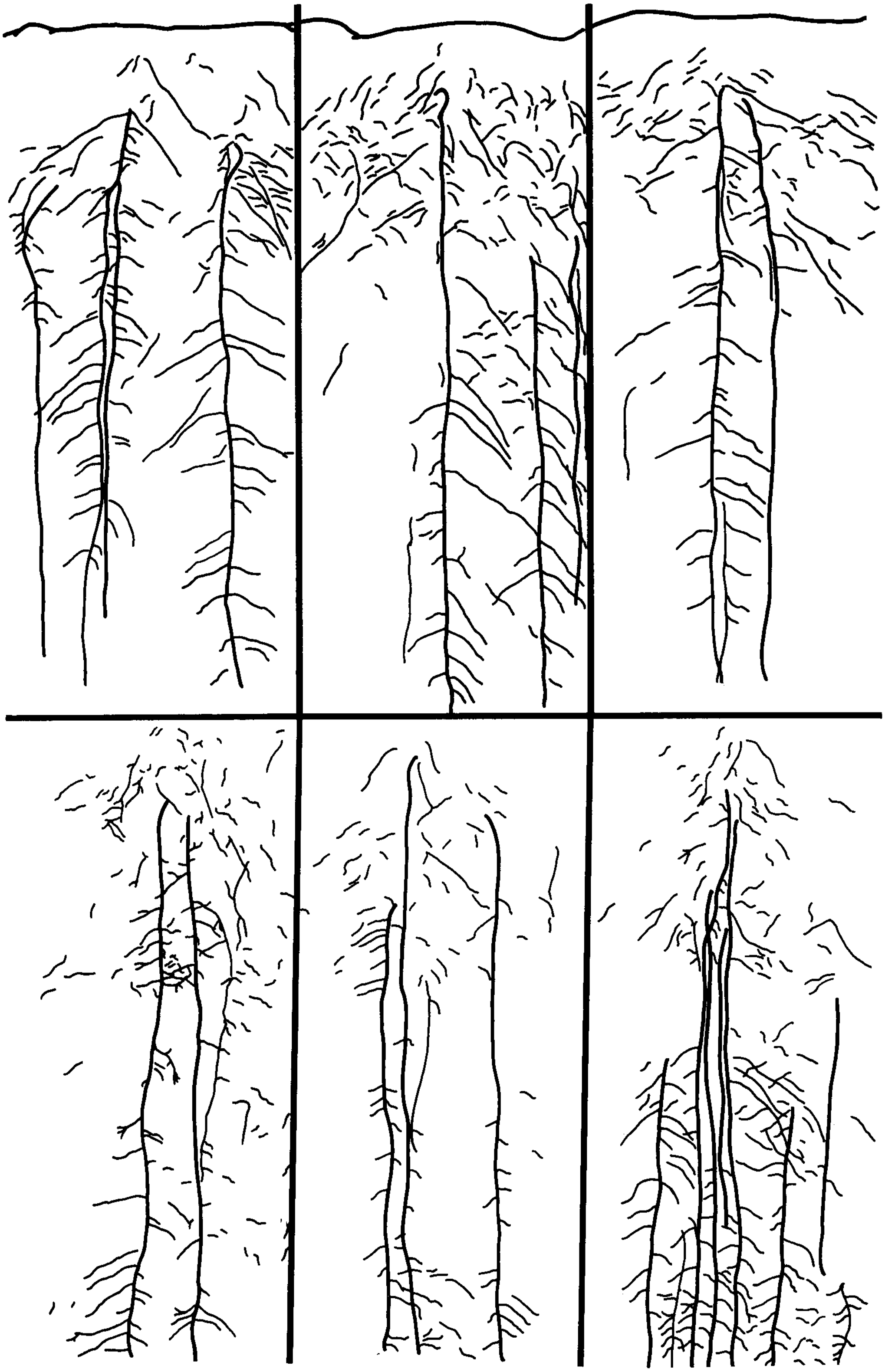

Figure 11. Root growth of birdsfoot trefoil when alfalfa flowered. Soil temperatures 12°C. and 24°C.; age 15 and 12 weeks (upper and lower). Left to right: 13.3, 26.6 and 40 pounds P per acre.

profuse at 24 than at 12°C. The better growth of roots at the medium P fertilization rate at 12°C. was not as evident as in earlier observations.

Root growth of both species at soil temperatures of 12 and 24°C, when alfalfa was flowering, is shown in Figures 10 and 11. Root growth of alfalfa was more profuse at the higher temperature. Root growth of birdsfoot trefoil appeared to be similar at both temperatures. The better growth response of roots, noted earlier, to the medium P fertilization rate at a soil temperature of 12°C., was no longer evident.

The data from root tracings agree, for the most part, quite closely with that obtained from weight measurements. Both sets of data show a greater growth of alfalfa than of birdsfoot trefoil roots. at both soil temperatures.

DISCUSSION

The data presented show that soil temperature is important to the growth of seedlings. Thus, it may be assumed that cultural modifications which influence soil temperature may determine, in part, the survival or death of seedlings. Slight modifications in temperature are probably of more importance to seedling growth in areas with cool springs, such as the Intermountain Region, than in more moderate climate.

Growth and elongation of alfalfa roots was greater than that of birdsfoot trefoil at all temperatures in this study. Similar results have been reported by Cooper and Ferguson (8, In press), who found roots of alfalfa and birdsfoot trefoil had penetrated to depths of 16 and 8 inches, respectively, in early August when grown with a companion crop. Visual observation in this experiment indicated that the rate of elongation of alfalfa roots was very rapid in comparison to birdsfoot trefoil during the initial growth phase. The rapid elongation of alfalfa seedling roots should favor its establishment in that it would be better able to survive surface soil drying.

The different response of alfalfa and birdsfoot trefoil to soil temperature, with respect to root-shoot ratios, is of interest. In alfalfa the distribution of dry matter into roots and shoots was not influenced materially by temperature. With birdsfoot trefoil, however, a greater proportion of synthate went into tops at higher temperatures than into roots. Some insight into these response differences may be obtained from the data of Smith (49, p. 75-79). He found that carbohydrate storage patterns of alfalfa and birdsfoot trefoil varied with cutting treatment and states, "Birdsfoot trefoil, after the initial vegetative expansion of early spring, apparently is dependent for growth primarily on carbohydrates synthesized by the existing top rather than on root reserves." Alfalfa, on the other hand, relies more on stored root reserves for new growth. From Smith's data it might be inferred that carbohydrate storage in birdsfoot trefoil occurs more in the crowns and basal stems than in the roots. If this inference is true, it explains, in part, the differences obtained between root-shoot ratios of species. The reasons for the occurrence of differences at high but not low soil temperatures is not clear.

On the basis of dry matter produced per $cm.^2$ of leaf area, birdsfoot trefoil was less efficient than alfalfa in dry matter production at all soil temperature levels. Since leaf area and dry matter were measured only at the end of the experiment, calculations of leaf area expansion and net assimilation rates are of questionable validity. Additional studies need to be made of growth analysis attributes of these two species, with periodic measurements made over a period of time.

Phosphorus applications to the low phosphorus Hazelair soils resulted in better root growth of both species, particularly at low temperatures. These results agree with other reports of the benefits of phosphorus to plants grown under low soil temperatures (1, p. 325-332) (28, p. 109-113). Phosphorus was not shown to be limiting in the field studies reported, but should be considered with respect to low soil temperatures on P deficient soils.

LIGHT STUDY--RESPONSE OF TWO-, FOUR-, AND SIX-WEEK OLD SEEDLINGS OF BIRDSFOOT TREFOIL AND ALFALFA TO DIFFERENT LEVELS OF LOW LIGHT INTENSITY

EXPERIMENTAL PROCEDURE

The experiment was initiated to determine if differences in light compensation points exist between species and if light compensation points vary with age of seedling. At two-week intervals, for a period of six weeks, Tana birdsfoot trefoil and Vernal alfalfa were each seeded into 40 "jiffy pots" (2½ by 2½ inch pots of peat moss composition) filled with plaster grade vermiculite. Pots were then placed into flats also filled with vermiculite. Following seeding, pots were placed in a growth chamber maintained at a day temperature of 75°F. and night temperature of 55°F. Length of photoperiod was 16 hours with a light intensity of 800 f.c. at bench level. At emergence plants of each species were thinned to five per pot. Pots were watered twice weekly from seedling emergence until the end of the experiment with a complete nutrient solution of the following composition:

Salt or acid	ppm. element in nutrient solution
$Ca(NO_3)_2.4\ H_2O$	Ca --- 200 N --- 140
$MgSO_4.7\ H_2O$	Mg --- 49 S --- 64
$Ca(H_2PO_4)_2.H_2O$	Ca --- 13 P --- 20
$MnCl_2.H_2O$	Mn --- 0.5
$CuCl_2.2\ H_2O$	Cu --- 0.02
$ZnCl_2$ (95%)	Zn --- 0.05
H_3BO_4	B --- 0.05

Between nutrient solution applications, pots received tap water as well.

At the end of six weeks, 40 pots of 2-, 4-, and 6-week old seedlings of each species were available for treatment. Each set of 40 pots was divided into 5 groups of 8 pots each. The five pots containing the tallest plants were assigned first - one to each group. Subsequent allocation to groups was on the basis of height until all pots were assigned. Height differences were estimated visually. One of each of four groups of each species was assigned to one of four light intensity treatments (200, 400, 600 and 800 f.c.) where they were grown for a 15-day period. Light intensity was regulated by cheese cloth shades of different numbers of layers. Tops of plants of the fifth group were harvested and separated into stem and leaf components which were oven dried and weighed. Roots were washed free of vermiculite, dried and weighed.

At the end of the 15-day light intensity treatments, all plants were separated into root, stem and leaf components and leaf area determined as previously described. Growth of plants was based upon weight of treated plants at the end of light treatment minus the weights of the plants sampled at the beginning of the light treatment.

RESULTS

Seedlings of both species increased in weight at all light intensities (Table 19). The distribution of the dry matter increase into roots, stems and leaves varied with light intensity and age of seedlings. With decreasing light intensity, the percentage of accumulated dry matter in roots decreased markedly (Figures 12 and 13). The decrease was most pronounced for two-week old seedlings grown with

Table 19: Weight increase of stems, roots and leaves of different age seedlings of birdsfoot trefoil and alfalfa when exposed to four levels of low light intensity for a 15-day period.

Species and initial age of seedling	Light intensity in f.c.			
	200	400	600	800
	mg.	mg.	mg.	mg.
	Roots			
Birdsfoot trefoil				
2 weeks	.5	2.4	10.0	12.0
4 weeks	3.9	11.7	32.9	20.7
6 weeks	8.2	63.5	106.1	85.5
Alfalfa				
2 weeks	- 3.5	9.4	19.6	27.1
4 weeks	9.3	26.1	41.0	45.3
6 weeks	2.1	161.3	240.8	210.2
	Stems			
Birdsfoot trefoil				
2 weeks	11.6	20.4	23.6	23.0
4 weeks	25.4	67.8	42.7	79.3
6 weeks	82.6	205.7	180.4	142.5
Alfalfa				
2 weeks	20.4	34.5	51.4	37.5
4 weeks	33.0	109.9	95.2	107.9
6 weeks	72.6	229.3	223.2	162.4
	Leaves			
Birdsfoot trefoil				
2 weeks	11.7	20.1	27.0	25.9
4 weeks	16.0	48.4	41.8	64.9
6 weeks	66.5	145.5	153.3	176.1
Alfalfa				
2 weeks	11.6	24.0	57.1	38.6
4 weeks	14.0	61.5	75.6	72.2
6 weeks	26.8	129.6	195.2	151.5
	Total			
Birdsfoot trefoil				
2 weeks	23.8	42.9	60.6	60.9
4 weeks	45.3	127.9	117.4	164.9
6 weeks	157.3	414.7	439.8	404.1
Alfalfa				
2 weeks	28.5	67.9	128.1	103.2
4 weeks	56.3	197.5	211.8	225.4
6 weeks	101.5	520.2	659.2	524.1

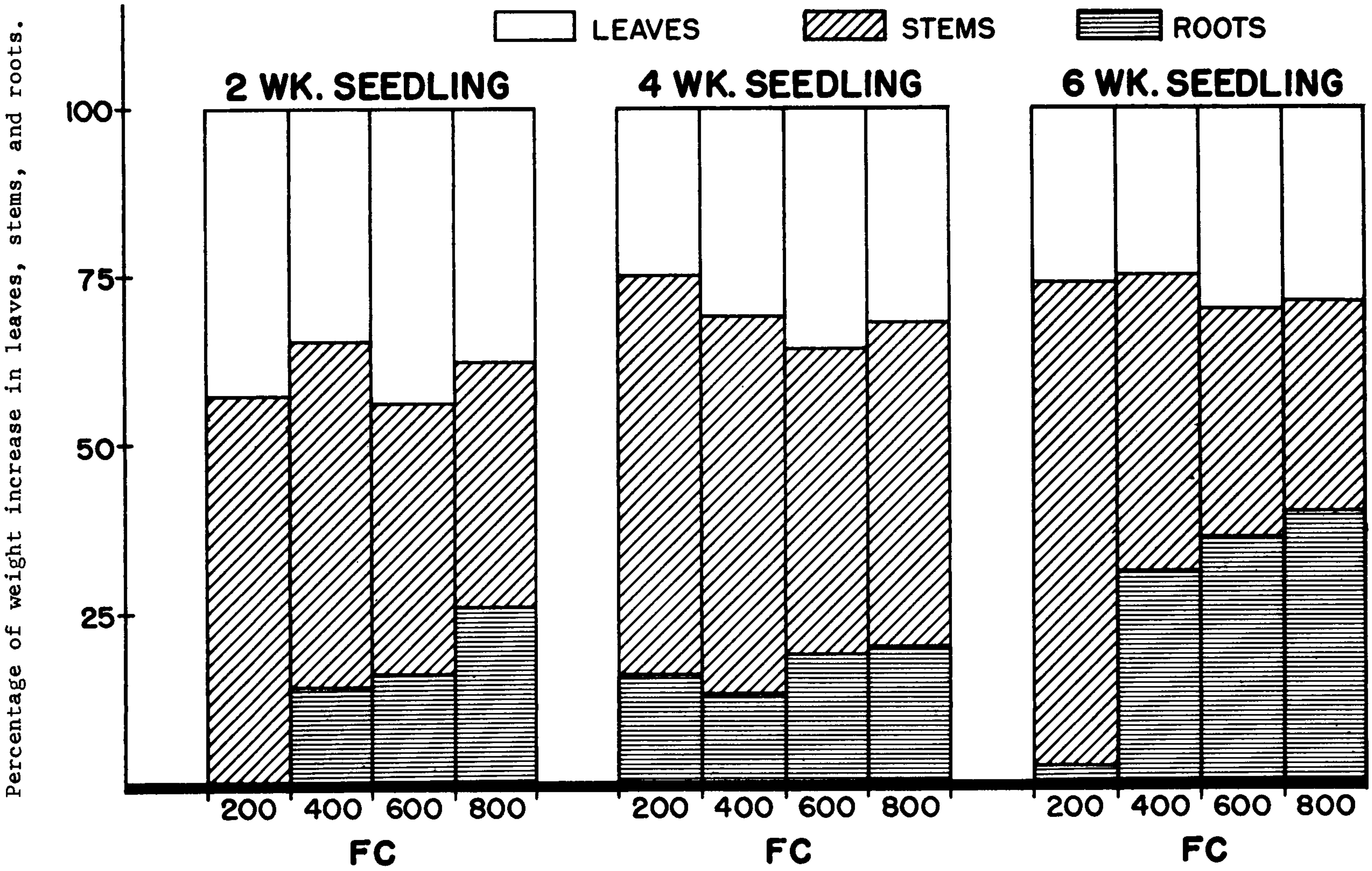

Figure 12. Distribution of dry matter increase in 2-, 4-, and 6-week old seedlings of alfalfa grown under 4 light intensities for a 15-day period.

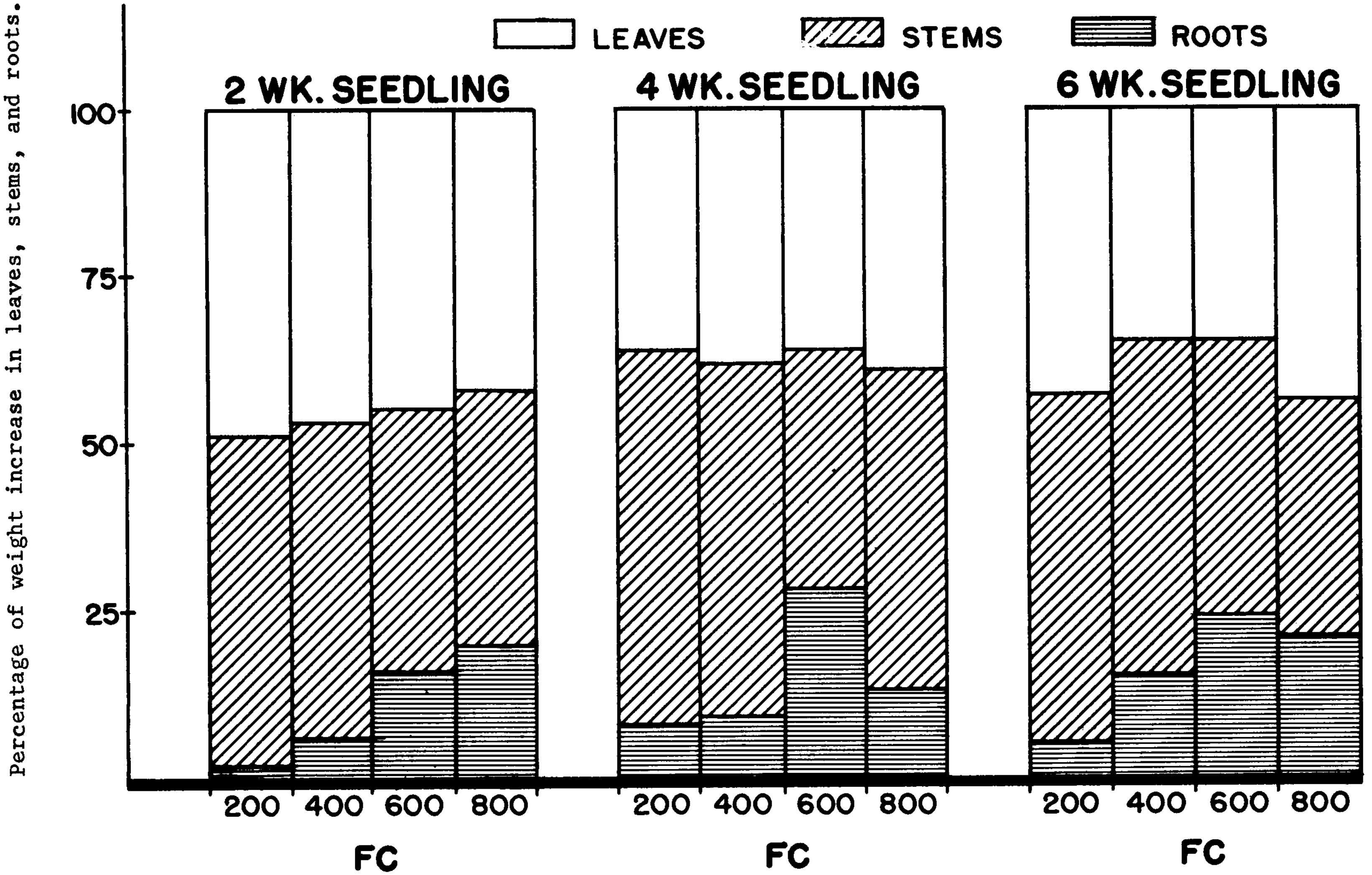

Figure 13. Distribution of dry matter increase in 2-, 4-, and 6-week old seedlings of birdsfoot trefoil grown under 4 light intensities for a 15-day period.

a light intensity of 200 f.c. Of the total dry matter increase of two-week old birdsfoot trefoil seedlings, only 2% accumulated in roots. Two-week old seedlings of alfalfa actually lost weight.

The percentage of dry matter increase going into stems increased with decreasing light intensity for seedlings of both species and all age groups (Figures 12 and 13). The greater proportion of synthate diverted to stems may be assumed to have been used primarily for stem elongation, since stems of plants at low light intensities showed the most elongation at the end of the experiment.

The percentage of accumulated dry matter going into leaves did not appear to be affected by age of seedling or by light intensity.

The data presented in Figures 12 and 13 show that with decreasing light intensity, accumulated dry matter is used by a plant primarily for stem elongation. The diversion of dry matter to stems is at the expense of the roots. The low dry matter accumulation, or lack of dry matter accumulation, of two-week old seedling roots introduces a new concept of light compensation points. In general, light compensation points of plants have been considered with respect to the whole plant. In this experiment, however, 200 f.c. might be considered to be the light compensation point of roots, but not of stems or leaves.

DISCUSSION

The classic concept of the term light compensation point envisions a light intensity at which accumulation of substrate by photosynthesis equals that which is being respired. Thus, plants could not increase in weight, although some growth could occur through utilizing stored substrate. In the experiment reported, both species continued to increase in weight at light intensities as low as 200 f.c. Therefore, the light compensation point of the plants as a whole was less than this value with the temperature regime used. At low light intensities, however, there was a shift in distribution of accumulated dry matter, with stem growth occuring at the expense of root growth. The trend was similar for both species. In the case of two-week old seedlings grown at 200 f.c., roots had a brownish, unhealthy appearance. If the treatment had been prolonged, death of these seedlings would probably have occurred.

From the data reported it would seem that while the light compensation point may define the intensity at which respiration equals photosynthesis, it does not define the point at which death of the seedling may occur. The dry matter accumulation of shoots at the expense of roots indicates that roots are more affected by low light intensity. While the immediate death of the plant may not occur as a result of root growth cessation, the plant would certainly have less ability to withstand adverse conditions such as drought in the surface soils.

Root dry matter accumulation of the youngest seedlings was most adversely affected by low light intensity. In this respect the data support that of Lin (23, 1-24), who reported a loss in dry matter of roots of trefoil seedlings shaded for a period of nine days following emergence. From these studies it may be concluded that low light intensity is more adverse to younger seedlings, which is in agreement with the early loss of seedlings in the field. Under actual field conditions, however, it is questionable whether or not light intensities during the very early establishment period would ever be as low as those tested in the growth chamber. In the field studies it was shown that seedlings established under barley received from 25% of the incident light in early morning to slightly over 50% at noon at the earliest sampling date. Under the high light intensities encountered in Montana, this amount should provide more than 1,000 f.c. most of the day, which exceeds the light intensities used in the growth chamber. Light intensity measurements in the field, however, are not as exacting as those under controlled conditions. With the measurement apparatus used, readings could only be taken between rows of barley. Intensities would be expected to be lower adjacent to, or within, a row. Furthermore, light conditions are constantly changing within a companion crop. A seedling may be in bright sunlight for a short period and subsequently in deep shade, depending upon the position of the sun. Effects of changing light intensities throughout the day have not been investigated.

The interrelationship of temperature and low light intensity on seedling growth was not studied. Investigations should be made of this relationship, since light compensation points are known to vary with temperature (37, p. 93-95).

RESPIRATION STUDY--COMPARATIVE OXYGEN UPTAKE OF GERMINATING ALFALFA AND BIRDSFOOT TREFOIL SEEDLINGS

EXPERIMENTAL PROCEDURE

Seeds of alfalfa and birdsfoot trefoil were placed on filter paper in covered petri dishes to which five ml. of water had been added. Seeds were then placed in a germinator held at a temperature of 30°C. At 12-hour intervals two seed lots of 100 seeds each (swollen or germinating seeds only) of each species were removed. These lots were placed in Warburg respirometer flasks with one ml. H_2O. Two ml. of 10% KoH were added to the center well. Flasks were then placed in a temperature bath at 30°C. and gas exchange measured. Calculations of oxygen uptake were based on standard manometric techniques (50, p. 1-6). Uptake was expressed on the basis of ul. O_2/hr./mg. dry weight.

RESULTS

Oxygen uptake of seeds of alfalfa and birdsfoot trefoil during germination is presented in Table 20. Values are not included for the 60-72 hour period, since deviations from linearity of the O_2 accumulation curves cast doubt upon their reliability. Deviations from linearity for this period may have been due to insufficient KoH to absorb the CO_2 given off by the larger seedlings. Oxygen uptake was not consistently greater for one species than another. During the first two periods uptake was similar for both species. At the third period O_2 uptake was greater for alfalfa, but the reverse was true

Table 20. Average* ul. O_2 uptake per hour per mg. of dry matter during four periods of seed germination.

Species	Sample period				
	12-24 hr.	24-36 hr.	36-48 hr.	48-60 hr.	Ave.
Birdsfoot trefoil	.69	.89	1.21	1.31	1.02
Alfalfa	.68	.80	1.34	1.18	1.00

* Each value in the table represents the accumulated O_2 uptake for a period divided by the number of hours within the period.

during the fourth period. Average O_2 uptake for the four periods was essentially identical.

DISCUSSION

On the basis of the results presented, the greater seedling vigor of alfalfa cannot be attributed to differences in respiratory metabolism on a unit dry weight basis. If one considers the respiration on a per plant basis, however, respiration by alfalfa would be greater than that of birdsfoot trefoil due to the greater amount of substrate in the larger alfalfa seeds. Size of seed has been shown to be related to subsequent growth. Black (2, p. 335-351) found that initial seed size was correlated with cotyledon and leaf area, regardless of the quantity of stored carbohydrates. In subsequent studies (3, p. 731-734), he showed that differences in early growth between strains of subterranean clover (Trifolium subterraneum L.) could be attributed to differences in size of seed. Seed size effects were maintained throughout the life of this clover.

In comparing alfalfa and birdsfoot trefoil one might expect the same sort of seed size relationship to exist between these species as Black found within a single species. The larger alfalfa seed produces larger cotyledons and initial leaves than birdsfoot trefoil, and thus has a larger total leaf area for photosynthesis. If one were to assume that leaf area expansion rate and net assimilation rate of both species were equal, alfalfa would be a much more productive species, purely on the basis of initial leaf area. Differences in seed size are genetic characteristics of these species.

Improvements of seedling vigor of birdsfoot trefoil might be made through breeding for large seed. The degree of improvement, however, would be limited to the range of genetic variability with respect to seed size.

SUMMARY AND CONCLUSIONS

Factors affecting the establishment, survival, and production of birdsfoot trefoil and alfalfa were studied in field, greenhouse, growth chamber and laboratory experiments.

In the field experiment the two legumes were seeded with orchardgrass in alternate 6-inch rows under 3 companion crop, 2 harvest management and 4 fertility treatments. Companion crop treatments were: (1) none, (2) barley seeded in 18-inch rows and (3) barley seeded in 6-inch rows. Seedling year harvest management practices were: (1) harvested to simulate pasturing and (2) harvested as grain or at the same time as grain. Fertility treatments were: (1) none, (2) 40 pounds of N per acre, (3) 35 pounds of P per acre and (4) 40 pounds of N and 35 pounds of P per acre. Seedings were made in 1960 and 1961. Grasses and legumes were seeded at a ½-inch depth in an east-west direction. Barley was seeded at right angles to the herbage species in a north-south direction. Redroot pigweed and pigeon grass seed was broadcast on the 1960 seedings at a rate of one pound per acre. Weeds were not seeded on 1961 seedings, since these plots were naturally infested with wild oats.

Measurements were made in the year of seeding of (1) percentage occupancy of legume seedlings, (2) light interception by the companion crop, (3) yields of herbage when clipped to simulate pasturing and (4) yields of herbage, weeds and barley at grain harvest. In subsequent years measurements were made of (1) percentage occupancy, (2) seasonal and total yields and (3) botanical composition.

Fertilizer treatments did not affect stands, survival, or production of grasses and legumes nor of the barley companion crop. The percentage occupancy of legume stands was decreased in proportion to the intensity of competition. Death of seedlings occurred very early in the establishment period and the degree of loss was similar for both species. Loss of seedlings was attributed to the effects of barley on the light and temperature factors of the micro-environment.

Following the initial stand loss, further losses did not occur during the growing season. Additional losses of birdsfoot trefoil plants occurred during the first winter when plants were established with a companion crop.

Companion crops inhibited the growth of surviving seedlings. Growth inhibition was attributed to reduced light intensity, since better growth of seedlings was obtained when barley was clipped frequently than when it was allowed to mature. In the absence of a companion crop, growth of seedlings was inhibited more by frequent clipping of thin weed stands than by allowing weeds to mature.

Yields of weeds were inversely proportional to the density of barley plants. In very weedy areas weeds might be expected to be as competitive toward seedlings as a companion crop. Wild oats was more detrimental to seedling growth than redroot pigweed or pigeon grass. The latter two species were more readily controlled by clipping.

Yields of herbage were reduced in years subsequent to seeding as a result of companion crop competition. Reductions in yield were attributed to decreases in stands of legumes and to growth inhibition in the seeding year. Yields were reduced to a greater degree and for a longer period of time when legumes had been established with barley matured to grain. Decreased yields of legumes were compensated for, in some cases, by increased yields of grass. Yields of grass grown with birdsfoot trefoil were significantly greater in the spring and less in the summer than yields of grass grown with alfalfa.

The influence of soil temperature and P fertilization on growth of birdsfoot trefoil and alfalfa was evaluated in the greenhouse. The two legumes were grown for a 90-day period with soil temperatures of 12, 18 and 24°C. and applications of 13.3, 26.6 and 40 pounds of P per acre. Measurements were made of root and top growth, of leaf area and of N and P content of herbage. Root tracings of plant roots growing between glass plates were also made during this period.

Root growth of both species increased with increasing temperature. At all temperatures the weight of alfalfa roots was approximately twice that of birdsfoot trefoil. Top growth of alfalfa increased in about the same proportion as roots with increasing temperature. Top growth of birdsfoot trefoil, however, increased markedly with increasing temperature. The greater growth of trefoil tops in comparison to roots resulted in reduced root-shoot ratios.

Birdsfoot trefoil produced less dry matter per $cm.^2$ of leaf area than alfalfa at all temperatures. Both species produced less dry matter per $cm.^2$ of leaf area at high than at low temperatures.

Root growth of both species increased with increasing levels of P fertilizer. Phosphorus was more important to root growth at low than at high temperatures.

Phosphorus content of tops of both species was greater at 24 than at 12 or 18°C. Phosphorus content of birdsfoot trefoil roots increased with increasing soil temperature, whereas that of alfalfa was similar at 12 and 18°C. and decreased at 24°C.

Nitrogen content of tops of both species was less at 18 than at either 12 or 24°C. Nitrogen content of tops was not affected by P applications, while that of roots decreased with increasing P levels.

The influence of light intensities of 200, 400, 600 and 800 f.c. upon growth of 2-, 4- and 6-week old seedlings of birdsfoot trefoil and alfalfa was studied in a growth chamber. The study was conducted under a 16-hour photoperiod with a day temperature of 75°F. and a night temperature of 55°F.

Seedlings gained weight at all light intensities. The distribution of accumulated dry matter, however, varied with light intensity and seedling age. With decreasing light intensity, the percentage of accumulated dry matter going into roots decreased markedly, while that going into stems increased. A smaller percentage of accumulated dry matter went into roots of two-week old seedlings than into roots of older seedlings. At 200 f.c. the percentage of dry matter going into roots of birdsfoot trefoil plants was negligible. Roots of two-week old alfalfa seedlings lost weight at 200 f.c. A light intensity of 200 f.c. was considered to be near the light compensation point for roots of two-week old seedlings under the temperature regime studied.

Respiration rates of germinating alfalfa and birdsfoot trefoil were determined for a 0-60 hour period. Oxygen uptake was measured manometrically and expressed on the basis of ul.O_2/hr./mg. dry weight.

Average oxygen uptake by the two species was quite similar on a per unit weight basis. On a per plant basis, oxygen uptake by alfalfa was greater, due to its greater size. Seed size differences in relation to seedling vigor and growth of these species was discussed.

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