Micrometeorological investigations in relation to forage crop production in Maryland

by
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INTRODUCTION

The behavior of plants is governed by their genetic constitution, the various chemical and physical processes occurring within plants and the general physiological limitations imposed on all organisms. The rediscovery of Mendel's work at the turn of the century stimulated research which led to a better understanding of the internal factors concerned with the course of individual development. The genetic constitution is vital to the ultimate form and characteristics produced but may not be expressed except by interaction with environmental factors. This paper deals with some of these environmental factors in relation to growth and development of forage crops grown under Maryland conditions.

Maryland's climatic conditions are unique through its location in a north-south transitional zone of the Eastern United States. By virtue of this location it is the approximate northern boundary for growth of such forage species as bermuda grass (*Cynodon dactylon* L.) and lespedeza (*Lespedeza spp.*) and the approximate southern boundary for such species as timothy (*Phleum pratense* L.), smooth bromegrass (*Bromus inermis* Leyss.), and birdsfoot trefoil (*Lotus corniculatus* L.). This uniqueness provides a diversity of climatic conditions and a broad range of plant species for study.

Meteorological observations in the past have been confined primarily to the aerial zone above a height of five feet. Observations made at this height, however, do not necessarily reflect the immediate environmental conditions of many growing plants. Geiger (31) writes,

> With the progress of science and especially with the increasing use of scientific data for economic purposes, new needs have arisen. The plan of the meteorological yearbooks is no longer sufficient. Indeed they have even proved misleading when used without further practical precautions. For instance, the number of frost-days, as published in the annuals, gives a false picture of the frost danger to agriculture. The published maximum temperatures are not authoritative in determining the heat available to grapes on the vine. It was soon found that all plants have their lives conditioned by that very zone of disturbance which has been so meticulously avoided in meteorological observations. Within this zone the prevailing climatic conditions are different from those at 2 meters height.

The necessity for studying the climate of the plant layer is, then, apparent if a full understanding of the effects of climate on plant behavior is to be gained.

Perennial forage plants persist for twelve months each year even though plant growth may be limited to a period from seven to nine months. It is important to carefully study the micro-environment of plants during the entire year. However, it is even more important to study this environment during periods of adversity.

The time of spring growth initiation is important to the farmer since it may mean added savings in his feed bill. Growth initiation at this time of year is governed primarily by temperature. An objective of this study was to gain further knowledge concerning temperature accumulation and initiation of spring growth of several forage species. Another objective was to investigate the relationship of increased temperature to the rate of growth.

Summer growth is often limited by the species' inability to grow during hot weather or by the lack of adequate, well distributed summer rainfall. These factors are of utmost importance in plant growth and stand survival of such plants as ladino clover and Kentucky bluegrass. An attempt was made to determine the combination of microclimatic factors which governed growth and stand survival.

Winter damage to ladino clover and other legumes has, in some years, been severe in many areas of the Northeastern United States. This injury often results from a combination of winter heaving, desiccation, and incidence of disease. An investigation of those factors most intimately correlated with this type of injury was another purpose of this study.

A number of important forage crop diseases appear to be correlated with climatic variations. For instance, the severity of Rhizoctonia root and crown rot (Rhizoctonia solani) on smooth bromegrass and birdsfoot trefoil appear to be closely associated with high temperatures and high humidity values. The relationship between environmental factors and incidence of disease can best be studied by investigating the actual environment in which the plants are growing, that of the microclimate.

These were the main objectives of this study. Some were covered in considerable detail while others, because of lack of equipment, time, etc., were studied less thoroughly. This problem was largely exploratory in nature. It was designed to attack some of the basic problems of forage crop production but in the main dealt with a survey of the possibilities and problems in a study of this nature.

REVIEW OF THE LITERATURE

The relationship of various climatic factors to the growth, development and distribution of plants has been the object of many investigations. An excellent coverage of this subject can be found in a number of reference books dealing with plant ecology including those by Weaver and Clements (93) in 1929, Lundegardh (52) in 1931, Klages (40) in 1942, and Daubenmire (23) in 1947. In addition to these publications Geiger's (30,31) two texts on microclimatology (1927 and 1950) give excellent reviews of work carried out in Germany and other European countries. These books deal largely with the aerial environment and its effect on plant behavior. A more recent book edited by Shaw (72) deals more with the edaphic factors in relation to the growth of higher plants, as well as soil microflora. All writers agree that in addition to soil variations the environmental factors most affecting plant response appear to be temperature, moisture, and light.

Various methods of classifying climates have been utilized in the past, and in each the importance of temperature has always been emphasized. Briggs, Kidd and West (15) found the increase in dry weight of the corn plant to be more closely correlated with temperature than with any other environmental factor. Lundegårdh (52) writes that "temperature is the master factor in the distribution of vegetation over the earth, though its action is always interwoven with those of light and water." Livingston and Livingston (47) have used temperature coefficients in their classification of climatic zones.

The difficulties in relating growth to such environmental factors as temperature, moisture and light become apparent when it is realized that growth is a complicated summation of a number of individual processes, each of which is also influenced by these factors in varying degrees.

Temperature affects the kinetic energy of the molecular system. It affects the solubility, diffusion and reaction velocities of chemicals. The enzymatic action, translocation and respiration processes in plants are all affected by temperature. Life is possible only within limits of certain temperatures and growth is confined to an even more narrow range. In general there are three cardinal points for plant growth. They are the maximum, minimum and optimum levels. These are not definite points, but integrate one into the other. They may also vary from one plant species to another. The topographic location and level at which these temperatures are obtained are also important factors to be considered in studying temperature and plant response. Geiger (30), Waterhouse (92), Ramdas (66), Wolfe (99), and many other workers have shown that annual extremes of weather factors may vary considerably in different plant communities and at different heights within the same plant community.

The official Weather Bureau records are obtained at a height five feet above the soil surface. This is often well above the height at which many agronomic crops grow. It is in this lower stratum of atmosphere (often spoken of as the "microclimatic layer") that the greatest amount of variations in temperature and other environmental factors occurs. With regard to temperature, extremely large lapse rates are found in the few centimeters next to the soil-air interface. It is thus at the soil surface or the surface of plant cover that the largest extremes in climate occur. Malurkar and Ramdas (53) report lapse rates of 112° F. per inch measured between 0.1 and 1.0 cm. above a hot steel plate, while between 1.0 and 10.0 cm. a difference of only 6° F. per inch was observed. Baum (5) reports the lapse rate to be greater in the cold than in the warm months and the air one-fourth foot to one foot above the ground to be warmer in the summer and colder in the winter than air at four to six feet above the ground. Waggoner (90) examined sources of variation for lapse rates and demonstrated that great differences in these rates can be and often are due to variations in methods of measurement. The inclusion or exclusion of the laminar layer and such factors as sky cover, soil type, time of day, plant cover, and wind speed all affect the steepness of the lapse rate. Because of the large differences that are often found between observations at the 60-inch and soil surface levels, more information is needed on the actual climate in which plants are growing. An excellent coverage of much of the work to date has been presented by Geiger (31) in his book, "Climate Near the Ground."

Both soil and air temperatures must be considered in relating temperature to plant response. It should be pointed out in this connection, however, that the soil absorbs more than 80 per cent of the sun's radiation which reaches the soil surface. Much of this is later reradiated to the surrounding air so that in reality air temperatures are produced by soil temperatures. Geiger (31) writes,

> Despite the enormous distance the sun rays have to pass through from the limit of the atmosphere down to the bottom of the atmosphere, a mighty radiation flux penetrates down to the earth's surface partly as direct sun radiation, partly as scattered radiation from the sky. The two together represent the main portion of the solar heat at the disposal of the economy of the earth and air. Wherever this immense energy current strikes upon the surface of the solid ground the radiation cannot penetrate this obstacle. A portion is reflected from the surface. Most of it is absorbed, changed into heat, and serves to raise the temperature of the ground.

In addition to its effect on air temperatures, soil temperature may be expected to influence shoot growth to the extent that it affects development and functioning of the root system. Because of the difficulties involved in studying roots, much less is known about their growth than has been learned about growth of the aerial organs of plants. The primary functions of the roots, besides supplying anchorage for the plant, are the absorption of water and inorganic salts and in some cases serve as storage organs. Temperature not only influences the growth of roots, but also the various absorption processes. Its effect on respiration may also have a bearing on efficiency of the root system to carry on its various functions.

The effect of low soil temperatures on decreasing the water absorption of plants has been known for some time. Excellent coverage of the problems of soil-plant-water relationships are given by Kramer (42), Crafts, Currier and Stocking (21), and Shaw (72) in books on this subject. It will not be discussed in detail in this paper. Clements and Martin (19), Duncan and Cooke (24), and Brown (17) found the absorption of water by sunflowers, sugar cane and other grasses to be greatly retarded by lowering the root temperature to a level approaching the minimum for growth. Kramer (41) states that this reduction is not only due to the physiological effects of low temperature on the permeability of the root cells but that the physical effects of increased viscosity and decreased vapor pressure also play an important role.

Let us now consider the effects of soil temperatures on the absorption of mineral nutrients by plant roots. It is generally agreed that energy must be expended by plant cells to bring about a transfer of solutes across a cytoplasmic membrane against a concentration gradient. It therefore seems reasonable that nutrient absorption would be affected by temperature since it affects the metabolic activity of the individual cells. Hoagland and Broyer (36) found the power of cells to accumulate given ions to be related to temperature. They point out that temperature coefficients for salt accumulations must be calculated indirectly inasmuch as salt absorption is dependent upon the metabolic activity of the roots. Other factors such as reduced viscosity of the protoplasm and increased mobility of the ions may be of importance. Many works have indicated that the absorption of solutes is reduced at low temperatures. However, it may be very difficult to separate the effects of low temperatures on the absorption processes from their effects on translocation and utilization of the nutrients once they are absorbed by the plants (Shaw (72)). It has been suggested by Went (94) and others that roots may exert a stimulating action on the growth of shoots which is not entirely dependent upon the absorptive functions of the root and perhaps attributable to a growth promoting substance developed in the roots. Nightingale (59) found nitrate nitrogen to be readily absorbed by plants when the temperature was near the minimum for plant growth. However, the reduction of these nitrates was greatly reduced or inhibited at these low temperatures.

The importance of temperature on dormancy and flowering of plants has been emphasized by Thompson (86), Post (64) and many others. It is a well-known fact that flowering habits of plants are controlled by such factors as their genetic make-up and the day length under which they are grown. However, these workers are quick to point out that day length may be altered in its influence on flowering by temperature effects. The importance of a balance between temperature and other climatic factors has been emphasized by Plitt (63), Tollingham (87), and many others.

Pearl, Edwards and Miner (60), and Edwards, Pearl and Gould (27) found the mean time rate of growth of Cucumis melo and Celosia cristata seedlings to be a parabolic function of temperature. As they increased the temperature, the period of maximum growth activity tended to fall earlier in the whole growth cycle. At low temperatures maximal growth rates came relatively late in the grand period of growth while at successively higher temperatures it came progressively earlier. Jones (38) reports that soil temperature controls chlorosis of gardenia and also affects growth rates and alteration of vegetative and reproductive phases of growth. A higher correlation was found between soil temperature and plant response than between air temperature and plant response. Brenchley and Singh (14) found that the garden pea (Pisum sativum L.) made good growth in hot air provided roots were kept cool. It was also found that unfavorable air temperature exerted less influence on plant growth than unfavorable root temperatures. Blackman (9) states that when average soil temperature was below 42° F. many species of grasses made no growth. They grew rapidly from 42° F. to 47° F. if nitrogen was added, while above 47° F. there was a marked increase in growth which was not greatly influenced by application of nitrogen fertilizer.

Many workers have observed that under normal growing conditions the carbohydrate level within the plant decreases as the surrounding temperature rises. The rate of photosynthesis appears to be relatively unaffected by temperature, whereas the rate of respiration increases rapidly with an increase in temperature. Low temperatures favor accumulation of photosynthetic products, while high temperatures may deplete the carbohydrate reserves. Brown (16), and Sullivan and Sprague (81) found this to be the case in a number of forage grasses. The work of Early and Cartter (25) suggests that as the organic materials required for growth are increased by an accelerated rate of photosynthesis (because of a greater incident radiation) root temperature may become an increasingly important limiting factor in shoot growth of plants. The interrelationships of these factors appears to be worthy of further study.

Harrison (35) grew Kentucky bluegrass (Poa pratensis L.) at 80° F. and after defoliation new leaves were produced which grew very rapidly. If clippings were sufficiently frequent this practice eliminated regrowth. At 60° F. the initial growth was slower but increased and was maintained throughout the experiment. When nitrogen was withheld little new growth was made between defoliations. Darrow (22) also found the greatest root and shoot growth at low temperatures (15° C.). The production of rhizomes appears to be associated with carbohydrate storage and under high temperature they are probably used up in respiration faster than they are being produced. At low temperatures top growth was bushy, tall, and succulent and the root systems were large, white, succulent, and coarsely branched, while at high temperatures the tops were short, erect, and nonsucculent and the roots were small, light brown, and densely tufted. Stuckey (80) also found a close relationship between development of colonial bent grass (Agrostis tenuis) and soil temperatures. In studying the effects of soil and air temperatures on growth and development of certain grass species Brown (16,17) found that, in general, these grasses were more sensitive to soil temperatures. Kentucky bluegrass (Poa pratensis L.) and orchard grass (Dactylis glomerata L.) made considerable growth at 40° F. (the lowest temperature used). The production of Kentucky bluegrass increased as temperature was elevated from 40° F. to 90° F. The optimum for top growth was between 80° F. and 90° F., while the optimum for root and rhizome growth was 60° F. The growth of orchard grass was somewhat similar but was less damaged by high soil temperatures than was Kentucky bluegrass.

In testing bromegrass clones under high temperatures Atwood and MacDonald (1) found that, in general, yields were higher at 70° F. than at 80° F. and 85° F. Carrol (18) reported high soil temperatures to be more destructive to turf grasses than similar air temperatures. Likewise low soil temperatures were more injurious than low air temperatures. White (96,97) grew excised root tips of wheat (Triticum vulgare) and tomatoes (Lycopersicon esculentum) in a nutrient media of sucrose, yeast extract and inorganic salts to study the effect of temperature on growth. The growth was measured after one week. The optimum for tomatoes of 30° C. was exceptionally sharp. The optimum for wheat was between 26° C. and 28° C. and not nearly so clear-cut.

Went (95) found that optimum growth of the tomato plant was obtained at 26.5° C. The greatest growth was obtained when day temperatures were 26.5° C. and night temperatures were 17 to 20° C. These low temperatures were only effective when maintained during darkness. The thermoperiodicity appears to be due to two different processes of which the dark process has a much lower optimum. It was suggested by this same investigator that this is a general phenomenon in higher plants. Along these same lines Ulrich (89) points out the importance of temperature and day length on the production of sucrose by the sugar beet (Beta vulgaris L.). He suggests that beets have no self-regulatory mechanism for sucrose accumulation but are dependent upon external stimuli directly or indirectly associated with a change in climate. This is particularly true with a lowering of night temperature coupled with a nitrogen deficiency.

The lowest temperature at which growth took place in root tips of Pisum sativum L. was found by Leitch (45) to be 28.4° F. However, she agrees with Lehenbauer (44) that at higher temperatures (above 87.8° F. for corn and 84.2° F. for peas) the initial growth rate is not maintained and a marked falling off in growth occurs during prolonged exposure. Their results support the opinion expressed by Lundegardh (52) that the van't Hoff rule has only a limited application to the temperature-growth curves for plants. He states that plants probably have different optimum temperatures for each stage of growth. Leitch (45) states that for seedlings of *Pisum sativum* at each higher temperature a different curve must be constructed for successive time intervals. The growth rate curve from -2° C. to 29° C. was not a van't Hoff reaction but a logarithmic type response. Between 30° and 40° C. the growth curves were not found to be simple time curves. In studying the influence of environmental factors on the growth of corn (*Zea mays* L.) plants under field conditions Eisele (28) found weekly increases in dry weight of maize plants to follow the autocatalytic type of curve for single plant hills, but that the curve was flattened almost to a straight line when constructed from data obtained in crowded plantings.

The definite relationship that exists between environment and plant growth has prompted many investigators to formulate mathematical expressions of plant growth in relation to the various environmental factors. As a result, such methods as the compound interest law proposed by Blackman (10), Reed's (67) differential equation for growth, the autocatalytic formula discussed by Robertson (70), and Thornthwaite's (88) temperature efficiency index have been devised in an effort to relate growth and environmental factors. These indices make no allowance for the existence of physiological limits. The physiological index is based on the researches reported by Lehenbauer (44) on the rates of elongation of maize shoots. He showed that the hourly rates of elongation of maize shoots exposed to maintained temperatures for a period of 12 hours were 0.09 mm. for 12° C., 1.11 mm. for 32° C., and 0.06 mm. for 43° C. under the conditions of his experiments. The physiological indices are determined from the smooth graph of the 12-hour exposure period. The physiological indices present a clear concept of the behavior of the maize plant under the particular environmental conditions maintained by Lehenbauer. However, this system also has limitations. Livingston (49) expresses it in the following words: "While it is quite apparent that the system of physiological indices here described is far superior, in several respects, to other systems heretofore suggested, it is equally clear that these indices are to be regarded as only a first approximation and that more physiological study will be required before they may be taken as generally applicable."

Under field conditions in 1939, Bair (2) found significant correlations between weekly growth rates of maize and Lehenbauer's physiological indices. This was not true in 1938 and he states that poor rainfall distribution probably accounted for this poor relationship. All of these temperature indices are more or less interrelated. Each has some particular advantage, if nothing more than simplicity, and each has some specific limitation either in actual determination or in broad application.

Studies thus far have succeeded in showing the great complexity of the growth and development of plants with relation to the environment in which they grow. All species do not behave alike under the same environmental factors and the same species may even behave differently at each stage of growth. The optimum for growth of different parts of the same plant may also be different. Edwards, Pearl, and Gould (26) report the optimum temperature for growth of Cucumis melo seedling hypocotyls to be 30° C., while the optimum for root growth is between 15° C. and 20° C. The response of hemp (Cannabis sativa) to differential soil and air temperatures as reported by Nelson (57) shows that maximum stem elongation occurs when high soil and air temperatures (30° C.) are maintained, while the highest dry weight was obtained with high soil temperatures (30° C.) and low air temperatures (15° C.). The lowest yields were obtained when this condition was reversed. A preponderance of male plants was obtained with high soil and air temperatures, while low soil and air temperatures produced more female plants. Hull (37) found high soil and air temperatures to be most beneficial in terms of dry weight yields of buckwheat (Fagopyrum esculentum) plants. He states that shoot temperatures appear primarily to regulate development while root temperatures influence chiefly the general growth processes of this species. Roberts and Struckmeyer (69) calculated characteristic top-root ratios for different species. These ratios were found to vary with changes in physiological conditions which were in turn associated with seasonal development of plants. Different light and temperature conditions did not have similar effects on the various species. They conclude that the condition within the tops is a large, if not the controlling, factor in the production of roots and thus the top-root ratio.

Wort (100) reported that plant heights, root lengths, and number of tillers of Marquis wheat decreased as soil temperatures were raised from 22° to 44° C. The greatest dry weights of tops and roots resulted in plants grown at a soil temperature of 22° C., the lowest maintained in the experiment. It was found that heading was accelerated as much as eleven days by increasing the soil temperature from 20° to 34° C. However, temperatures above 34° C. retarded or prevented heading entirely. Hammond and Kirkham (34) found dry matter accumulation in soybeans (Glycine max) both in the greenhouse and in the field to be composed of three exponential segments which coincided with three distinct plant growth stages. Similarly dry weights versus time curves of four varieties of corn grown for two different years in the field showed growth curves to be made up of a series of four exponential segments which coincided with four growth stages of the plant. In both cases the last break appeared to mark the end of vegetative expansion.

The practical applications of studies dealing with crop plants and the environment in which they grow is becoming more evident. Katz (39) has used heat unit accumulations in determining planting and harvesting dates for canning peas. Temperature records from Madison and field data from Columbus, Wisconsin for a three-year period were used. A linear relationship was found between heat unit accumulations and tenderometer readings. Tenderometer readings are a function of growth. Both direct summation and exponential methods were used. The difference between these two methods was found to be small.

Shaw and Thom (73,74) found intervals between emergence and tasseling of corn to be very important in determining maturity dates. A one degree rise in average temperature for the 60 days after planting resulted in a three-day shortening of the interval. Accurate predictions were difficult before silking time. Maturity was defined as time of reaching maximum dry weight. Over a four-year period the intervals between silking and maturity for three varieties was almost constant, and because of this the maturity date could be rather accurately predicted. By using this prediction of maturity date and by preparing a graph showing the probability of frost occurrence for each remaining day of the season the percentage of soft corn could be estimated with a high degree of accuracy.

Attempts of workers to forecast disease epidemics of various sorts have been underway for some time. The first potato blight forecasting service in the United States was recently developed by Melhus (55) and others in the Upper Mississippi Valley region. In 1946 and 1947 Cook (20) forecasted the occurrence of tomato blight in Eastern Virginia. His forecasts were based on the appearance of late blight in relation to the temperature and rainfall for May, June and July over a 17-year period.

Over large areas with similar temperature conditions the relative abundance of available moisture has more pronounced effect on the vegetation and on the adaptability of the area, or any part of it, to crop production than does any other single factor of the environment. Barger and Thom (4) have used rainfall records and corn yields from six Iowa counties to characterize drought. The criterion of drought intensity was based on the amount of rainfall which will just permit normal corn development during a period of N consecutive weeks and is the minimum total required rainfall for that span. Correlations between maximum rainfall deficits and deviations of county corn yields from the long-time weighted average for that county were made. They indicated that for years in which drought conditions occurred from 25 to 60 per cent of the total variation in yield was explained by this criterion. In studying correlations between precipitation and yields of corn in the Northern Great Plains, Pengra (62) found correlation coefficients for the precipitation during the growing season to be much higher than those before the growing season. The reverse was found in the case of small grains in which preseasonal correlations were higher. Swanson (82) has used precipitation distribution, ranges of temperature and other climatic factors to obtain weather patterns for areas of the Central Great Plains. He states that these patterns are not infallible but are useful in planning a cropping system and as an aid in development of new adapted varieties of field crops. They are also valuable in interpretations of crop performance. Precipitation is only important insofar as it makes possible adequate soil moisture for the growth of plants. Available soil moisture is considered to be the water retained in the soil between the extremes of field capacity and permanent wilting percentage. Under Southern Illinois conditions McKibben, Gard, Van Doren, and Fuelleman (54) report that when rainfall dropped below two inches in two weeks during the summer, additional moisture had to be applied to maintain maximum growth of grass-legume pastures in Southern Illinois. These are only a few examples of the applications of meteorological investigations as related to crop production.

The influence of light intensity and quality upon growth of plants has been studied in some detail. Shirley (76) grew plants in the greenhouse and outside under a series of shades provided with forced ventilation and found almost a straight line relationship between dry weight and increasing light intensity during the winter with sunflowers and *Galensoga* spp. During the summer the relationships were described by a curve which approached the horizontal at higher light intensities or more than 50 per cent of full sunlight. With *Geum* spp. and buckwheat the slope decreased at lower intensities. More dry matter was produced by plants studied when the complete spectrum was utilized than under any portion of it. The leaf area of the cucumber (*Cucumis sativus*) was found by Gregory (32) to be more dependent upon light than upon temperature. However, 63° F. was the lowest temperature used and this may have been above the critical temperature for this species.

Gregory (33) reports relative leaf growth rate and net assimilation to be independent. In crowded barley plantings larger leaf surfaces were associated with a decrease in net assimilation if plants were grown under reduced light intensities. At other times decreasing relative leaf growth rates were associated with steady assimilation rates. The investigator states that the optimum for leaf growth appeared to be at a lower light intensity. Blackman and Matthaei (8) have shown the rate of photosynthesis with low light intensities to be almost directly proportional to light intensities providing other factors are not limiting. However, at higher intensities this relationship does not hold. The intensity of light is difficult to evaluate. Both the quantity and quality of light reaching plants must be considered. Photoelectric cells and recording equipment are needed and recommended for continuous records and evaluation of light factors. Such equipment is described by Segelken (71), Shelford and Kunz (75), and Sprague and Williams (78). A summary of the performance of integrating phototube recorders has been reported by Somers and Hammer (77).

No literature dealing with light relationships of mature forage stands was found but the importance of light to growth of young stands which are growing with a companion or nurse crop should not be overlooked. Pritchett and Nelson (69) grew alfalfa (Medicago sativa) and bromegrass in the greenhouse with light ranging from 2823 foot-candles to 157 foot-candles. The latter condition was found in the field where new oat varieties were grown under high nitrogen fertilization. They found the dry weights of plants to decrease as light intensity decreased. Roots were affected to a larger extent than shoots. No response to nitrogen application was obtained when the foot candles were 422 or less. Nodulation of alfalfa was inhibited at 257 foot-candles but was resumed when the shades were removed. Flanagan and Washko (29) found higher red clover (Trifolium pratense) populations and less loss of stand of red clover and alfalfa with higher light readings. Because of differences in leafiness a considerable difference was found between small grains used in their ability to allow light penetration to the small legume seedlings beneath the grain canopy.

In addition to temperature and its effect on growth and development of plants many studies have been made on winter hardiness of plants. A rather complete review of winter hardiness of plants along with current theories as to the causes of injury and resistance of certain plants has been compiled by Levitt (46). Winter hardiness is often considered synonymous with cold resistance. In this connection Lamb (43) points out that winter injury may also be due to secondary effects of low temperatures, such as smothering under ice or tightly packed snow, or upheaval of plants due to alternate freezing and thawing. He states, "in the soft wheat belt of the Northeastern United States, it is only in exceptional seasons that winter wheat is killed by the direct effect of low temperatures. In the opinion of workers long associated with this area, the most common cause of injury is probably heaving; that is, the pulling of the plants from the soil when the surface is raised by frost action." Taber (83,84) found that soils differ greatly in amount and rate of heaving and that the same soil behaves differently under different conditions of freezing. He states that heaving pressure is often greater than can be explained by expansion alone. It is due to the segregation of water as it freezes. Pressure effects accompanying the freezing of soils are due to the growth of ice crystals and not to changes in volume. Pressure is developed in the direction of crystal growth which is determined chiefly by the direction of cooling. Crystals grow in those directions in which they are in contact with undercooled water. Heat is conducted away from the growing ice crystal. He gives the chief factors controlling segregation (formation of ice crystals) as the size of soil particles, amount of available water, size and percentage of voids, and rate of cooling. Second and subsequent freezes are more serious because the soil is left loose and expanded by previous frost action. In the laboratory he measured heaving pressures as high as 2.3 tons per square foot. He claims that the maximum pressure, although not measured, "must have been well over 14 tons per square foot." Bouyoucos (11) states that the true explanation appears to be that heaving is caused, almost entirely, by the drawing and accumulation of water at or near the soil surface brought about by the force of crystallization. This frozen water grows upward in the form of massive capillary ice columns, pillars, ridges, or solid sheets of ice. As the water is pulled to the point of freezing and as these different forms of ice grow they push upward. This in general underlies nearly all phenomena of soil, plant, and pavement heaving. He states that in the case of plants these ice crystals attach themselves very tightly to plant root or crown and as the crystals melt the plant roots are left exposed. Munichsdorfer (56) states that the energy for crystal formation is supplied by removal of heat. The growth of ice layers does not take place along lines of least resistance but in the direction of heat removal. Excellent reviews of the mechanics of heaving and conditions necessary for its occurrence are given by Munichsdorfer (56) and Bouyoucos (11).

MATERIALS AND METHODS

This study was undertaken first to obtain data for the Northeastern regional forage strain and variety testing program. At each participating station a set of standard weather and edaphic observations were to be made over a pure Kentucky bluegrass sod which was kept clipped at approximately a two-inch level. Secondly, this study was undertaken to learn more about the growth, development, and behavior of forage crops under Maryland conditions.

In addition to measurements in the Kentucky bluegrass sod, observations were made in orchard grass, ladino clover, orchard grass-ladino clover mixture, bromegrass-ladino clover mixture, alfalfa, and bare-ground plots. The alfalfa was cut at the hay stage, while the remaining species, except Kentucky bluegrass, were harvested at the silage stage. Continuous soil and air temperature records were obtained in these plots by using a 16-point recording potentiometer shown in Figure 1. Near the end of the experiment the recorder was equipped with a time clock which enabled the operator to obtain only the desired temperature records. Previous to this the machine printed continuously and as a result only one out of every 16 cycles of printing was used. After this change any interval from 10 to 120 minutes could be selected, thus making it possible to record only the data desired. This offered considerable saving in charts, and

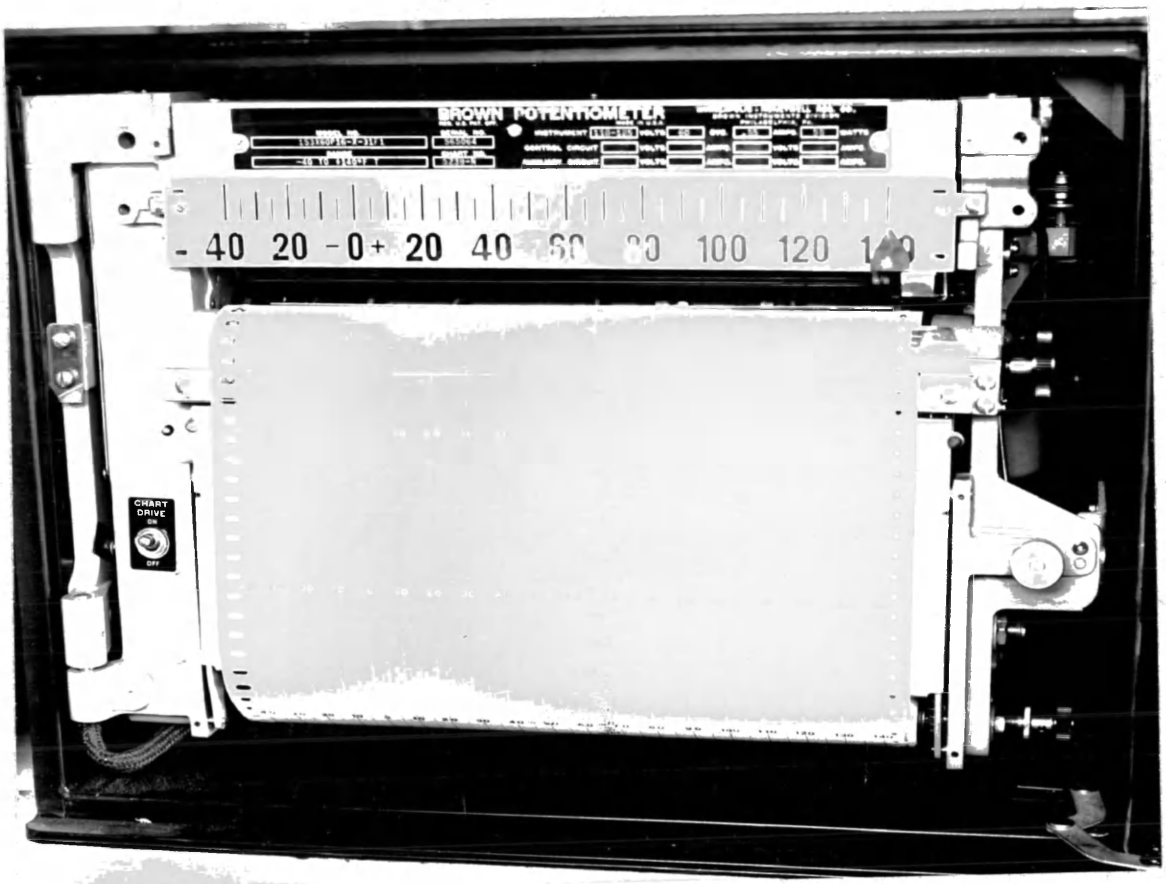


Figure 1. Recording potentiometer used in this study

transformation of records from charts to data sheets was much easier. The instrument is always energized so that erroneous readings do not result. Only the printing and chart drive mechanisms were halted. The modifications necessary for installation of this clock were made by Mr. G. F. Whelahan, who was a Washington representative of the Brown Instrument Company.

Periodic spot check readings were made with a portable potentiometer. This instrument had a range of 10.1 millivolts covered by a 10-point dial switch having steps of 1.0 millivolts and a scale of 220 divisions. In addition, it had provisions for automatic compensation of the range junction temperature when connected to copper-constantan thermocouple lead posts. It could also be used as a standard potentiometer for measuring any e.m.f., in which case the reference junction would be inoperative.

Soil temperatures were obtained at 10-inch, 3-inch, and one-half inch depths while air temperatures were obtained at 3 inches, 12 inches, and 60 inches above the soil surface. It was not possible to obtain continuous records at all of these levels in each plot since only 16 points were available on the recording instrument. These locations were occasionally changed to meet special situations. The only thermocouples that were not changed were those located in and above the uniform Kentucky bluegrass sod. They remained connected to the recorder throughout the experimental period.

A panoramic view of the area showing the anemometer, recording rain gauge and standard Weather Bureau shelter, which housed a hygrothermograph and standard maximum-minimum thermometers can be seen in Figure 2. The small building in the center houses the recorder and other instruments. The thermocouple lead-in wires were taken overhead from the building to the various locations. This enabled machinery to move freely over the plot areas without causing damage to the wires. These lines leading to each plot were attached to a junction box enclosed by a metal housing shown in Figure 3. The thermocouples from the various soil and air levels were attached to the other side of the junction box. This arrangement enabled easy removal of the thermocouple for repair, should it be damaged, without having to replace the entire lead-in wire. It also made the system more flexible in that the recorder points could be easily shifted from one location to another without disturbing the thermocouples embedded in the soil. This was a savings in materials as well as labor. Such an arrangement did not alter the thermocouple reading. A thermocouple was formed on each side of the junction box, but since these two points were essentially at the same temperature, equal potentials were produced by each. These potentials were in opposite directions and therefore tended to counteract one another; thus the true potential for the circuit was not changed. Number 20 gauge copper-constantan wire was used for these couples. These two wires were bound together to form one compact cable.

Figure 2. Panoramic view of the experimental area during the winter months. All recording instruments are housed in small building on the right

Figure 3. Close-up showing junction box, location of thermocouples above the soil surface and wires leading to the soil moisture blocks

Small metal shields were placed over each thermocouple used to obtain air temperatures. This protected the element from direct radiation from the sun. The shields were painted with a dull white paint and left open at the bottom and both ends to allow for adequate air ventilation. The thermocouples placed in the soil were embedded in a glass tube approximately one and one-half inches long which was filled with solder. Care was taken to see that no air spaces were left in the glass tube around the thermocouple which would act as an insulator thus producing a slight lag in temperature recordings for these points. The wire itself was encased in an acid resistant plastic tubing which was pushed into the open end of the glass tube. This kept the wires dry and free from corrosive action while in the soil. The plastic tubing fit very tightly and could not be used to cover wires longer than three to four feet. In such cases several wires were led underground through a larger metal pipe. The plastic covering was used only to protect the lead wires from the base of the pipe to the protected thermocouple. Para-wax and calking compound were used to seal the ends of the pipe against entrance of moisture. Thermocouples in the soil used for spot check readings were constructed so that they could be easily attached to the portable potentiometer.

For sampling air temperatures the device shown in Figure 4 was used. The temperature at any level could be obtained by turning the selector switch to the desired level. It was light and easily transferred from one location to the other

Figure 4. Instruments for sampling soil and air temperatures

Short metal pegs in the ends of each leg kept it upright. For random sampling of soil surface temperatures a probe with thermocouple embedded in the tip was used. This is shown in the center of the picture to the left of the potentiometer.

Soil moisture was obtained by using plaster of paris resistance blocks with two electrodes embedded inside. Resistance readings were obtained with an alternating current impedance meter similar to the ones described by Bouyoucos (12, 13). The arrangement of these moisture blocks and of the thermocouples in relation to the soil profile can be seen in Figure 5. Moisture percentages were obtained at 3-inch, 10-inch, and 18-inch levels of each plot. Differently colored wires were used at each level for ease in identification. These were read twice weekly, or whenever a change in moisture occurred. An attempt was made to get readings just before, and just after each rain to more completely evaluate the soil moisture relationships.

Evaporation rates were measured during the summer months. This was accomplished by using black and white spherical atmometer bulbs described by Livingston (50). The evaporation rates were observed in the different forage mixtures and at various levels within each sward. The latter technique was undertaken to get some idea of the magnitude and steepness of the evaporation-transpiration gradient found within and above different types of plant cover. The arrangement of these bulbs can be seen in Figure 6. Each bottle was equipped

Figure 5. Soil profile for the area showing the location of moisture blocks and thermocouples. Portable potentiometer shown in the background.

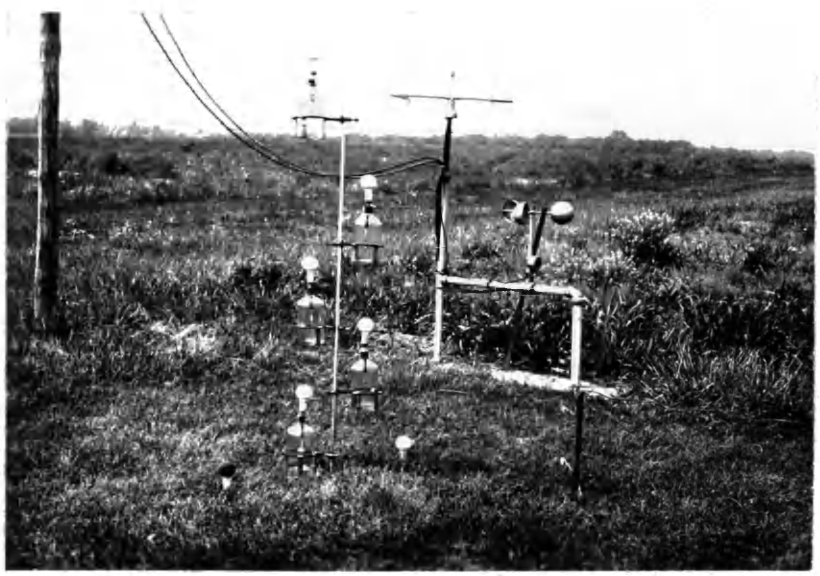


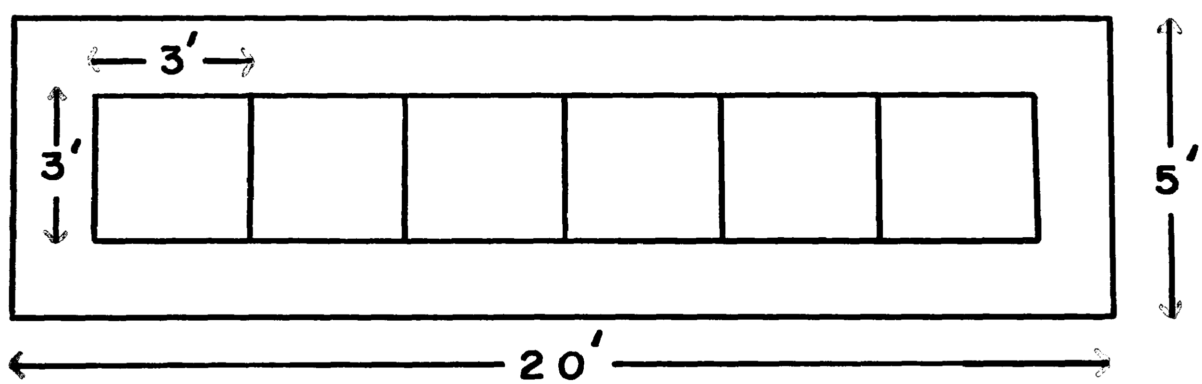
Figure 6. Arrangement of atmometer bulbs used to measure evaporation rates

with a mercury trap to prevent rain water from entering the porous sphere. The bottles were weighed each day to determine the amount of water lost. This was more accurate than a volumetric measure, providing care was exercised to insure that the outside of the bottle was dry before weighing. Humidity readings were obtained with a hygrothermograph and hand aspirated psychrometer. A Dewcel unit for obtaining dew point readings was also used to a limited extent. An attempt was made to adapt this unit for use with the recording potentiometer by soldering a small thermocouple to the resistance bulb thermometer which was housed in the sensitive element. This was successful except that the temperatures were outside the range of the recording instrument. It could not be used for continuous recordings without modifying the recorder and therefore was not used extensively.

A limited study of light penetration and sampling of light readings was undertaken. An instrument for obtaining continuous light records was not available for this study. A portable Weston light meter was used to make the sampling study. The meter had three ranges of zero to 10, zero to one thousand, and zero to ten thousand foot-candles. The sensitive selenium cell was attached to a long extension cord and hermetically sealed so that it could be placed in wet herbage, if necessary, without damage to the unit. In order to place the element at the desired position in the plot with the least disturbance to the herbage a 12-foot, light weight, metal wand was constructed. This wand is shown in Figure 7 along with the light meter. The pointed end allowed for easy penetration through the herbage. Calibrations on the handle allowed for accurate placement of the element in the herbage.

Figure 7. Light meter and metal wand used in making illumination measurements.

It was felt that [illegible] the various climatic fact[ors] [illegible] [sho]uld be included in a stu[dy] [illegible]. [illegible] to determin[e] [illegible] from area described the actual values over the entire plot and obtain a measure of the variability that existed among readings. To reduce the sampling error each plot was stratified into six equal parts as shown in Figure [illegible]. [An a]rea of 3 by 18 feet was used for these sampling measurements with each block being three feet square. [illegible] were [taken] at two randomly located [points] [illegible] block. [illegible] and the points [illegible] each zones. [illegible] [illegible] [illegible] coordinates [illegible] block. [illegible]



[illegible] [illegible]. Plot [illegible] taken at each point located in this manner. The variance was measured as follows:

$$s_u^2 = \sum_{i=1}^{m} \tfrac{1}{2} (X_1 - X_2)_i^2 / k \qquad \text{(A)}$$

where x_1 and x_2 were the two random temperature readings within each block and k was the number of blocks. The standard error is then

$$s_{\bar{X}} = \sqrt{s_u^2 / n} \qquad \text{(B)}$$

where n is the total number of observations.

The same procedure was used in studying the variations that exist in light readings. However, in this case a slightly different approach was made. After each reading was taken in the forage another was immediately taken on the zenith of the sky. Ratios of illumination in the forage to sky illumination were then computed. It was felt that a series of diurnal samplings at suitable intervals of growth could make possible the conversion of continuous measurements of sky illumination to that found within the herbage. It also seemed desirable to investigate the number of such ratios that must be obtained for reliable estimates of light penetration in a forage of this type. Light readings were taken only in the yield strip from each plot. Since this length was only 17 feet long the area could not be easily divided into six equal blocks. Two blocks on either end were two and one-half feet in length while the center four were three feet. Since the strata were of different area weighting had to be employed in estimating both the mean and the variance. If the weights are defined as

$$w_i = \frac{\text{area of } i^{th} \text{ stratum}}{\text{total area of plot}} \tag{C}$$

then the weighted mean is obtained as follows:

$$\overline{X}_w = \sum_{i=1}^{m} w_i \ \overline{X}_i \tag{D}$$

This is an unbiased estimate of the ratio over the plot. The variance of an individual stratum was obtained by

$$s^2_{u_i} = \frac{1}{2} (X_1 - X_2)^2 \tag{E}$$

and the total variance then becomes

$$s^2_u = \sum_{i=1}^{m} w_i^2 \ s^2_{u_i} \tag{F}$$

A detailed analysis of this sort of data is given by Thom (85) in a paper on the design of meteorological experiments.

The information described above was collected, summarized, and an attempt made to interpret plant response in terms of these data. Early spring growth, drought susceptibility, and winter survival of certain species were the factors considered in most detail.

During the early spring months of 1951 and 1952 plant growth was measured each week. A temperature-growth index was calculated for the corresponding period. Growth rates were obtained by choosing twelve "average" plants in a 5- by 20-foot plot. Leaves from each plant were marked before spring growth started and their average leaf elongation was used as a criterion of growth. The leaves were identified and initial location of leaf tips were marked on a small stake adjacent to the leaf to be measured. The elongation of these leaves was accurately measured every seven days by the use of calipers. The same leaf was used throughout the period of study which was from February 27 to May 23 in 1951, and March 5 to May 23 in 1952.

Various methods of relating growth to temperature change were studied. Correlations were calculated between growth and values obtained by various methods of condensing and averaging temperature data. The daily average temperatures were obtained in two ways. The first method was to average the daily maximum and minimum temperatures; the second to obtain the average using two-hour readings throughout the day and night. Temperature indices were calculated using the exponential and other temperature-growth formulae previously mentioned. Wakeley and Rigney (91) suggest that all weather data should be on punch cards so that all types of frequency distributions could be made and their relations to plant growth better understood. Frequency distributions of two-hour temperature readings were prepared from these data. These frequencies were plotted for each level within each plot, first using day and night temperatures separately and then the 24-hour totals. This, it was felt, allowed for a more accurate evaluation of the critical temperature for growth of these species, i.e. the temperature at which growth of these species appeared to begin in the spring and the effectiveness of each added increment of temperature. This approach was used to obtain, if possible, the effect of duration and frequency of temperatures on plant response rather than merely considering the maximum, minimum or average temperature for a given period. Initiation and rate of growth were studied in this manner.

Benecke and Jost (7), in citing the work of Talma, point out the importance of this time element. With a short exposure of three and one-half hours <u>Lepidium sativum</u> showed an optimum temperature at 30° C. and an optimum of 29° C. when this time was doubled. The highest rate of activity was at 27.2° C. with an exposure time of 14 hours. Newhall (58) states that a method used to predict growth should take into consideration daily temperature rather than an overall average for the entire interval. Pearson (61) considered daylight temperatures more effective than low night temperatures in correlating temperatures with plant responses. He considered two-hour recordings to be adequate for this type of study. Since there undoubtedly was some difference between the day and night temperatures with respect to growth, they were first considered separately and then combined.

Temperature-growth indices were calculated from these frequencies by using the following formula:

$$G = \sum_{i=1}^{n} F_t \ (T_i - B) \qquad \text{(G)}$$

where: G is the temperature-growth index

F_t is the frequency of a temperature occurrence

T is the temperature at any two-hour interval

B is the base temperature

n is the number of observations for a given period

Base temperatures of 38, 40, 42, 44, 46, 48, 50, and 60 degrees F. were considered. A base of 40° F. was eventually chosen as being the most effective and was used throughout the experiment. Indices were also calculated from these frequency distributions by modifying the growth formula used by Livingston and Livingston (47) which was as follows:

$$U = 2^{\frac{t-40}{18}} \qquad \text{(H)}$$

When the frequency of temperature occurrence is incorporated, this formula becomes:

$$U = \sum_{i=1}^{n} F_t \ 2^{\frac{T_i - B}{18}} \qquad \text{(I)}$$

where: U is the temperature-growth index

F_t is the frequency of a given temperature occurrence

T is the temperature at any two-hour reading

B is the base temperature

n is the number of temperature observations for a given period

No attempt was made to correlate temperature and growth during the summer months since other factors become more limiting for growth at this time than temperature. An attempt was made to relate the survival of ladino clover stands to summer drought, winter heaving and incidence of disease. A series of photographs was taken of these plots throughout the year. This gave a pictorial story of the behavior of the plants. Yield data, a record of rainfall, soil moisture percentage, and temperature at the various levels gave a rather complete story of this situation. During the winter months records were made of the amount and frequency of heaving. This was studied in relation to the extent, swiftness and duration of freezing under various types of plant cover and on bare ground. The instrument shown in Figure 9 was used to measure the amount of heaving that took place. Wooden doweling with diameters of one-fourth inch, three-eighths inch, one-half inch, and one inch were used. These were placed in the ground at 4, 8, 12, and 16 inches. The instrument was designed to be moved from plot to plot. Metal pipes were placed in the soil at a depth of three to four feet, which was well below the frost line in the area. These were used as sockets for the support of the instrument. A reading was taken on each pipe in the fall and again in the spring with a transit from a standard location to determine if any

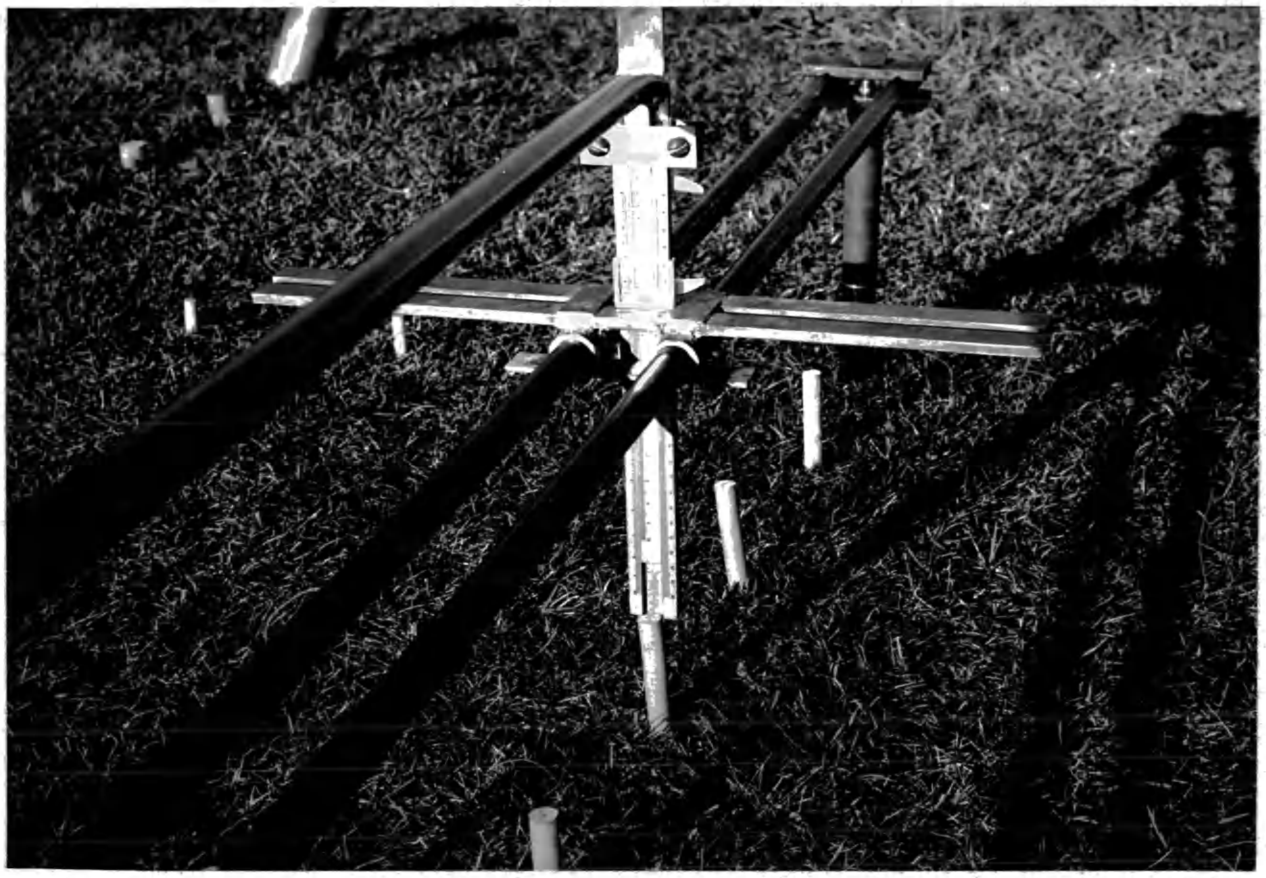


Figure 9. Instrument used to measure the amount of heaving. The arrangement of permanent pipes and wooden doweling is also shown.

movement of these pipes had occurred during this period. Movement of plants and the doweling was obtained by determining the distance from the instrument arm to the top of the peg or a marked point on a plant. By attaching the rule to a long handle the operator could stay off the plot when making these measurements. The same slide rule caliper was used here as was used in measuring leaf elongation. Small juice cans were placed over the permanent pipes when not in use to prevent ice and snow from collecting in them.

A measure of the magnitude of the experimental error involved in heaving measurements within a single plot was obtained for all species and mixtures of species included in the experiment. The wooden doweling were placed systematically in each plot. This was necessary in order to use the measuring equipment to best advantage. The total variance for a single plot was obtained with the following formula which removes the autocorrelation effect by differencing

$$S^2 = \tfrac{1}{2}\ (X_1-X_2)^2 + (X_3-X_4)^2 \cdots + (X_7-X_8)^2 + \tfrac{1}{2}\ (X_2-X_3)^2 + (X_4-X_5)^2 \cdots + (X_1-X_8)^2 \qquad (J)$$

where X_1 to X_8 were the total seasonal heaving values for individual pegs within a single plot. Hence, the sampling unit variance is

$$S_u^2 = S^2/k \qquad (K)$$

where k is the number of blocks or groups of pegs differenced sets of two. The standard error is, then,

$$E = \sqrt{s_n^2 / n} \qquad (5)$$

where n is the number of heaving observations.

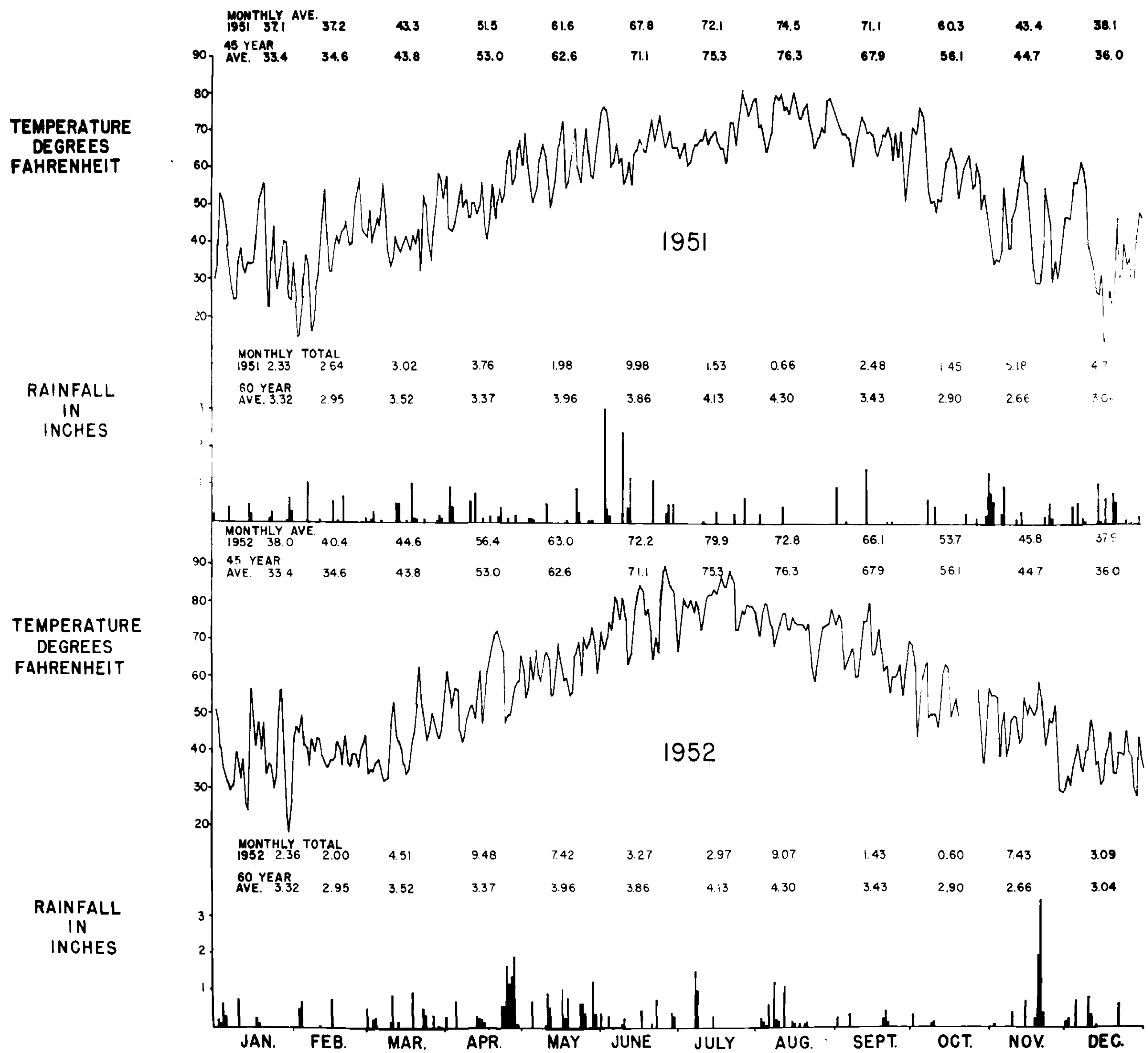
EXPERIMENTAL RESULTS

Weather and Forage Crop Production

The climatic conditions which prevailed during the course of this study were extremely varied. This was fortunate since it made possible a study of plant growth and behavior over a wide range of conditions. The monthly temperature and precipitation records for College Park representing 60-year averages are presented in Figure 10, along with monthly and daily temperature and precipitation records at the Plant Research Farm, College Park, Maryland for the years 1951 and 1952 during which time this study was conducted.

The rainfall during the late summer and early fall months of 1950 was near normal. This resulted in excellent fall growth of orchard grass, ladino clover and other forage grasses and legumes. In contrast to these conditions precipitation was extremely sparse from July through October of the following year. These conditions resulted in very poor fall growth of most forage species. A comparison of both fall and spring growth as well as the proportions of clover in the sward is shown for these two years in Figure 11. The mixture of grass and clover was maintained the first year, but the clover was virtually eliminated the following winter. Ladino clover was entirely eliminated in many areas whether it was grown alone or with an associated grass. These losses of clover stands appeared to be the result of a combination of several

Figure 10. SUMMARY OF TEMPERATURE AND PRECIPITATION AT THE PLANT RESEARCH FARM, COLLEGE PARK, MARYLAND



Fall 1950

Spring 1951

Fall 1951

Spring 1952

Figure 11. Fall and spring growth of orchard grass and ladino clover from 1950 to 1952

major factors. Some of the more important factors appeared to be the severe late summer drought, poor fall growth, excessive winter injury, and a high incidence of disease.

Let us now consider in some detail the conditions that brought about this large difference in growth and stand persistence. Precipitation throughout the winter and early spring months of 1950-51 was near normal. However, a drought of short duration did occur during the latter part of May. This did not result in severe damage to any of the plantings although ladino clover, especially in plantings with orchard grass, was beginning to show signs of water stress during hot afternoons. The orchard grass was at this time 18 to 20 inches high, while the ladino clover in this association was on the average only 8 to 12 inches above the ground. Although the monthly average temperature for May was below normal, there were several warm days during which temperatures of 100° to 105° F. were measured at the top of the ladino plants within the orchard grass-ladino plantings. This was often an increase of from 10 to 20 degrees above the temperatures outside of the herbage at a height of five feet, which is the usual level for standard air temperature measurements.

Rainfall during June was nearly three times the normal rate for this time of year. This, coupled with slightly below normal temperatures, resulted in nearly ideal conditions for growth of forage crops. Because of these conditions extremely high yields were obtained for the first two harvests. All plants made good recovery immediately following the second harvest but exceptionally low rainfall from the latter part of June until the first part of November retarded growth of ladino clover especially. The few surviving plants of the legumes were undoubtedly maintained at the expense of their root and stolon reserves which left them in a very weakened condition going into the winter months. Only 0.66 inches of rainfall fell during August. This was 3.64 inches below the long-time average for the locality. Many of the light showers that did occur throughout this period succeeded only in moistening the top inch or two of soil. Much of this moisture evaporated directly from the soil surface and foliage and did not effectively replenish the steadily declining soil moisture supply. This resulted in essentially no yield of either the grass or legume for the last harvest, as shown in Table 1. Even though the third harvest added very little to the total seasonal yields for 1951 they were higher than those for the previous season. This was, of course, due to the very heavy growth before the first two harvests. A pictorial story of the growth of orchard grass and ladino clover during this season can be seen in Figure 12 which shows the luxuriant growth of both species for the first two harvests and the very sparse, dried up growth for the latter part of the season. Note the large amount of clover that has been eliminated by the middle of August. The orchard grass is also showing considerable damage. This drought condition lasted throughout the fall period, and these plants were not able to make any appreciable growth before the winter period began.

Table 1. Forage yields of orchard grass, ladino clover, and alfalfa for the three-year period, 1950-1952 inclusive. Yields in tons per acre at 12 per cent moisture

Harvest	Ladino Clover 1/			Orchard Grass 2/			Orchard-Ladino 3/			Alfalfa 4/		
	1950	1951	1952	1950	1951	1952	1950	1951	1952	1950	1951	1952
1	.23	.98	.10	1.13	2.16	2.58	1.14	1.79	1.40	1.60	1.79	1.87
2	.34	.86	.06	1.16	.87	1.28	1.06	1.12	.49	.48	1.31	.24
3	.32	.04	.11	.88	.24	.40	.62	.21	.29	.49	.55	.41
4						.36			.32			
TOTALS	.89	1.88	.27	3.17	3.27	4.62	2.82	3.12	2.50	2.57	3.65	2.52

1/ Average of 2 plots

2/ Average of 3 plots

3/ Average of 5 plots

4/ Average of 2 plots

first harvest

second harvest

third harvest

Figure 12. Growth of orchard grass and ladino clover during the summer of 1951

Note the high proportion of clover eliminated from the sward by the time of the third harvest and the limited growth made by the orchard grass.

Precipitation was at or above normal throughout the winter months that followed, and soil moistures were increased and maintained at a high level throughout this period. The high levels of soil moisture increased the tendency for heaving of ladino clover stolons. Most of the few plants remaining after the fall drought period were not able to survive the severe winter conditions. The heaving and subsequent exposure of roots and stolons was followed by a week or more of cold, dry winds which dried out the exposed plant parts. This was followed by about two weeks of warm, moist weather which was conducive to development of such crown and root rot organisms as Sclerotinia trifoliorum Eriks., which took a heavy toll of the remaining plants. A result of these conditions is depicted in Figure 11, where the ladino clover has been completely eliminated from the orchard grass-ladino clover associations. The same thing occurred where ladino clover was grown alone.

Graphic presentations of the soil moisture conditions in some of these plots from July through December 1951 are given in Figures 13 and 14. The general trends shown here were typical of those obtained in plots containing other species or mixture of species. The soil moisture levels were high in the early part of July following the heavy, frequent rains that occurred during June. Following this period of plentiful moisture conditions the lack of adequate rainfall to replenish the soil moisture supply resulted in

Figure 13.

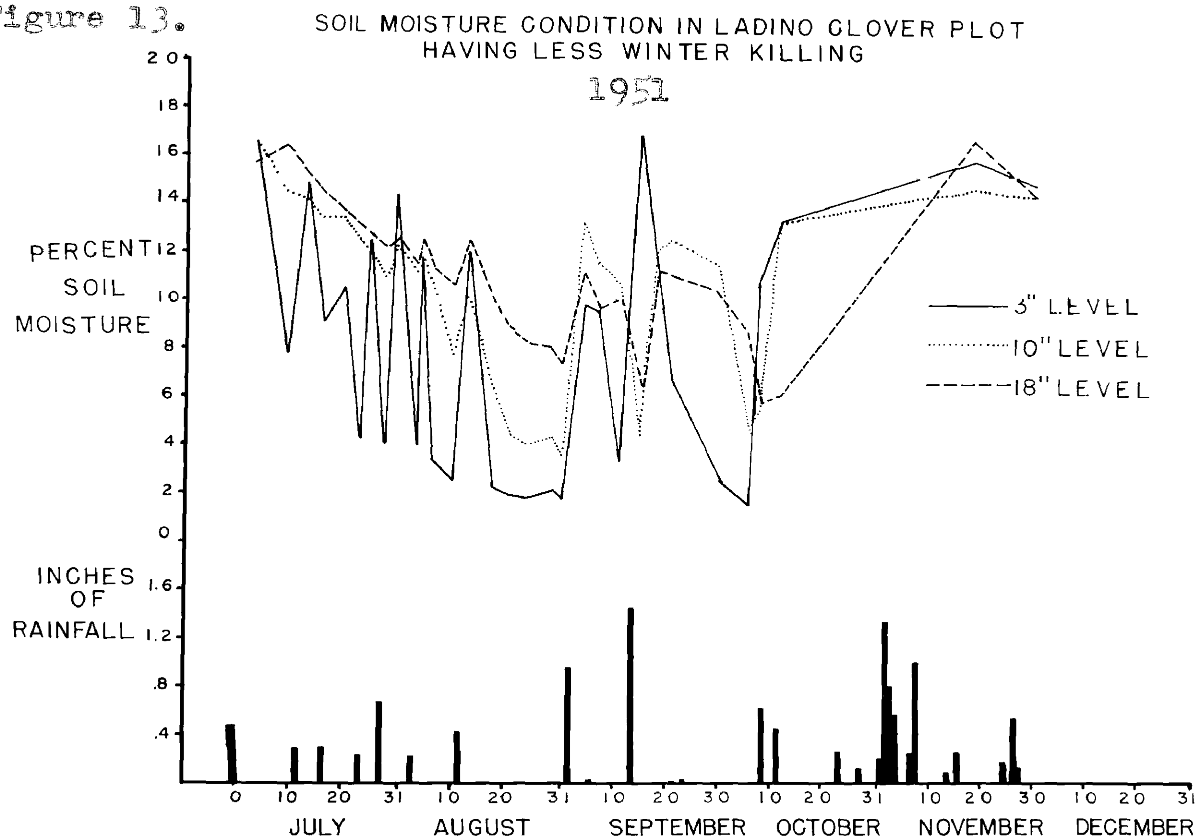
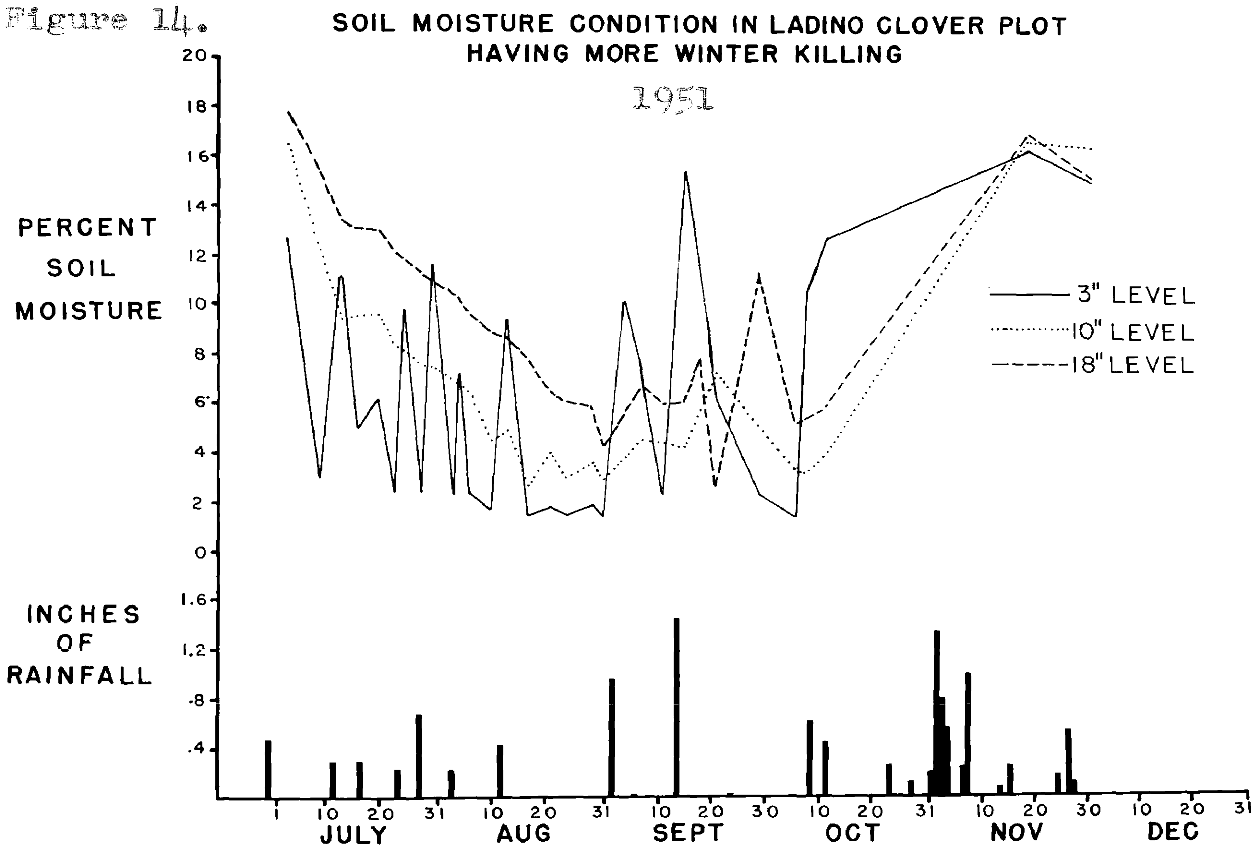


Figure 14.



a steady decline in the available soil moisture especially at the more shallow depths.

In some plots the soil moisture percentages at the 18-inch level, as well as at the more shallow depths, was at or near the wilting point during the latter part of the summer. The permanent wilting percentage for this soil was approximately five per cent. Although moisture levels at the three-inch depth were affected by rains of as little as 0.1 to 0.2 inches, the 10-inch and particularly 18-inch depths were only slightly affected. The rains during most of the summer were so light that moisture penetration was seldom more than an inch or two.

It was observed that the survival of ladino clover was noticeably higher on those plots where the soil moisture also remained at higher levels during the summer months. A comparison of the soil moisture percentages at the 10- and 18-inch levels is presented in Figures 15 and 16. It should be noted that the moisture percentages are consistently higher in those plots where stand survival was greater. The differences in stand survival coincided very closely with the available moisture supply. This is shown in Figures 17 and 18. The soil moisture conditions in Figure 14 were measured in the area shown in Figure 18. The soil moisture levels shown in Figure 13 were measured in the area shown in Figure 17. More favorable moisture conditions were noted in this latter area. Consequently a larger percentage of ladino clover survived the summer drought and the surviving

Figure 15. COMPARISON OF SOIL MOISTURE AT TEN-INCH LEVEL IN TWO LADINO CLOVER PLOTS

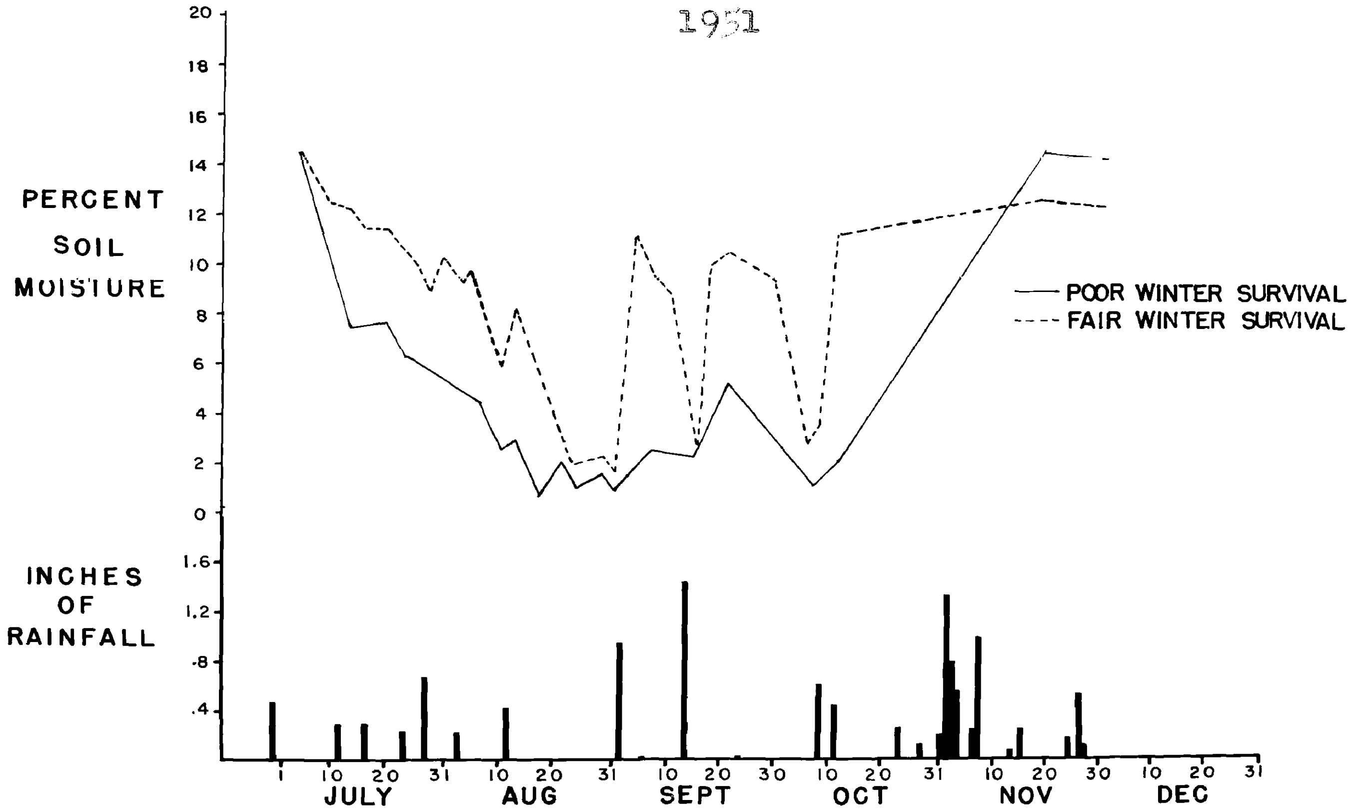
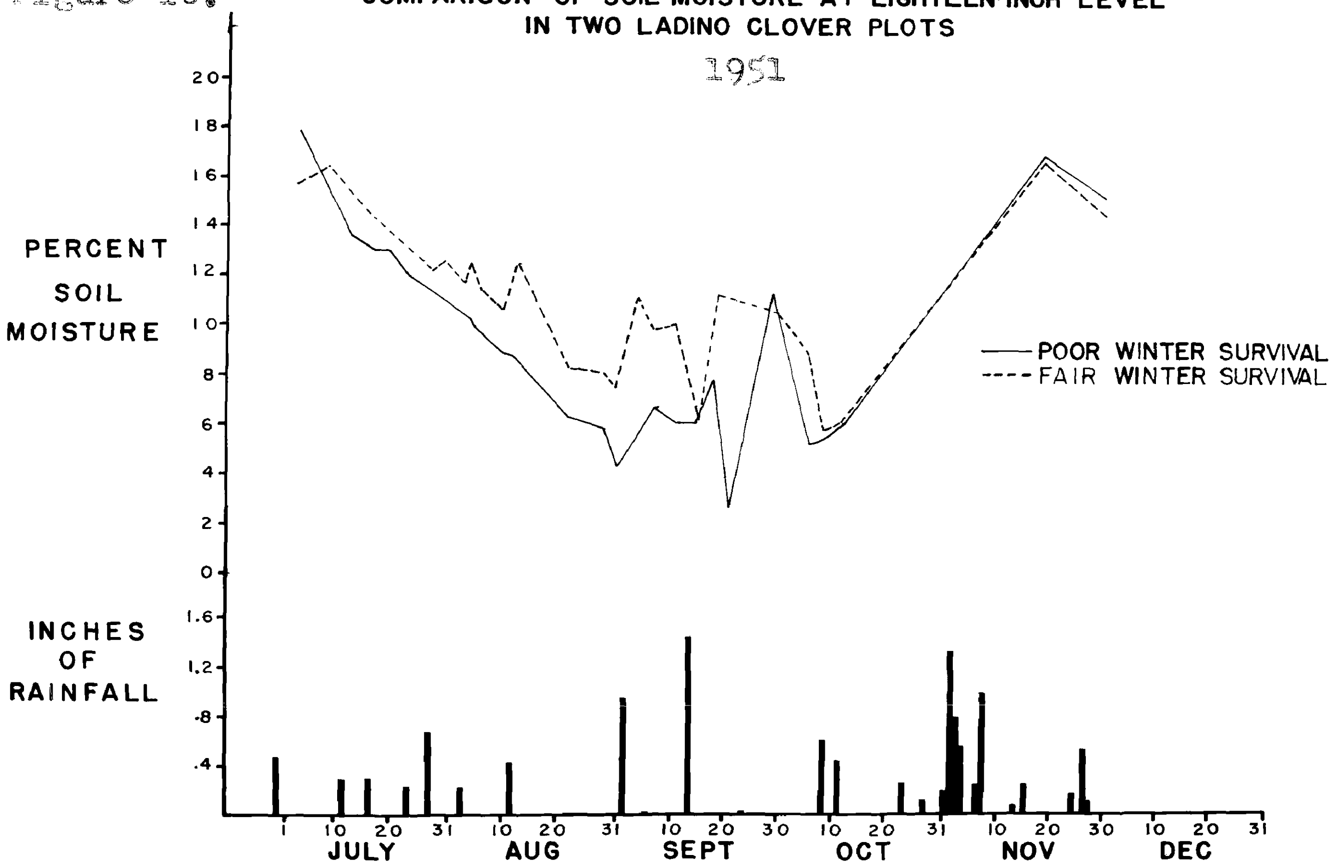
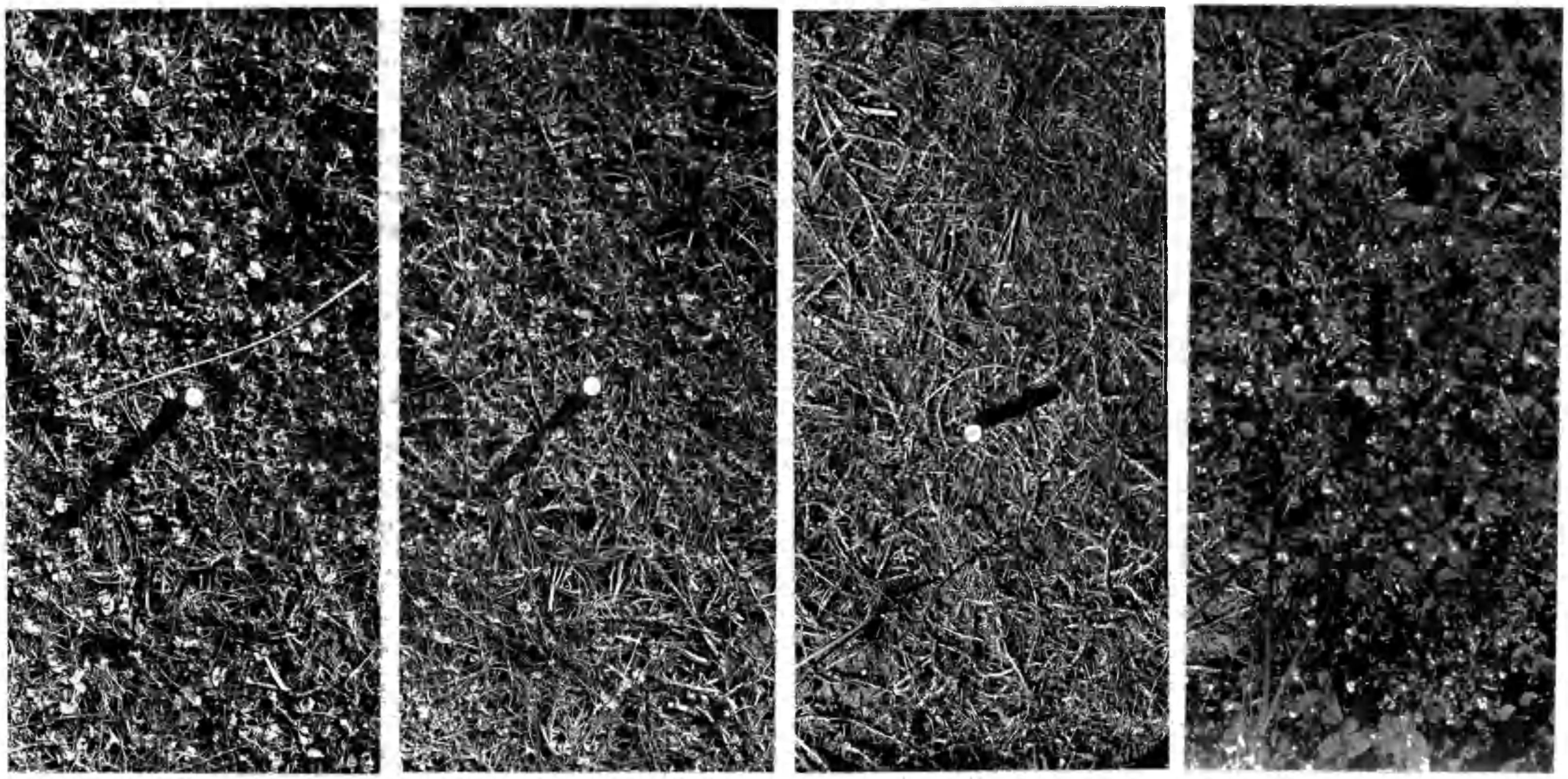


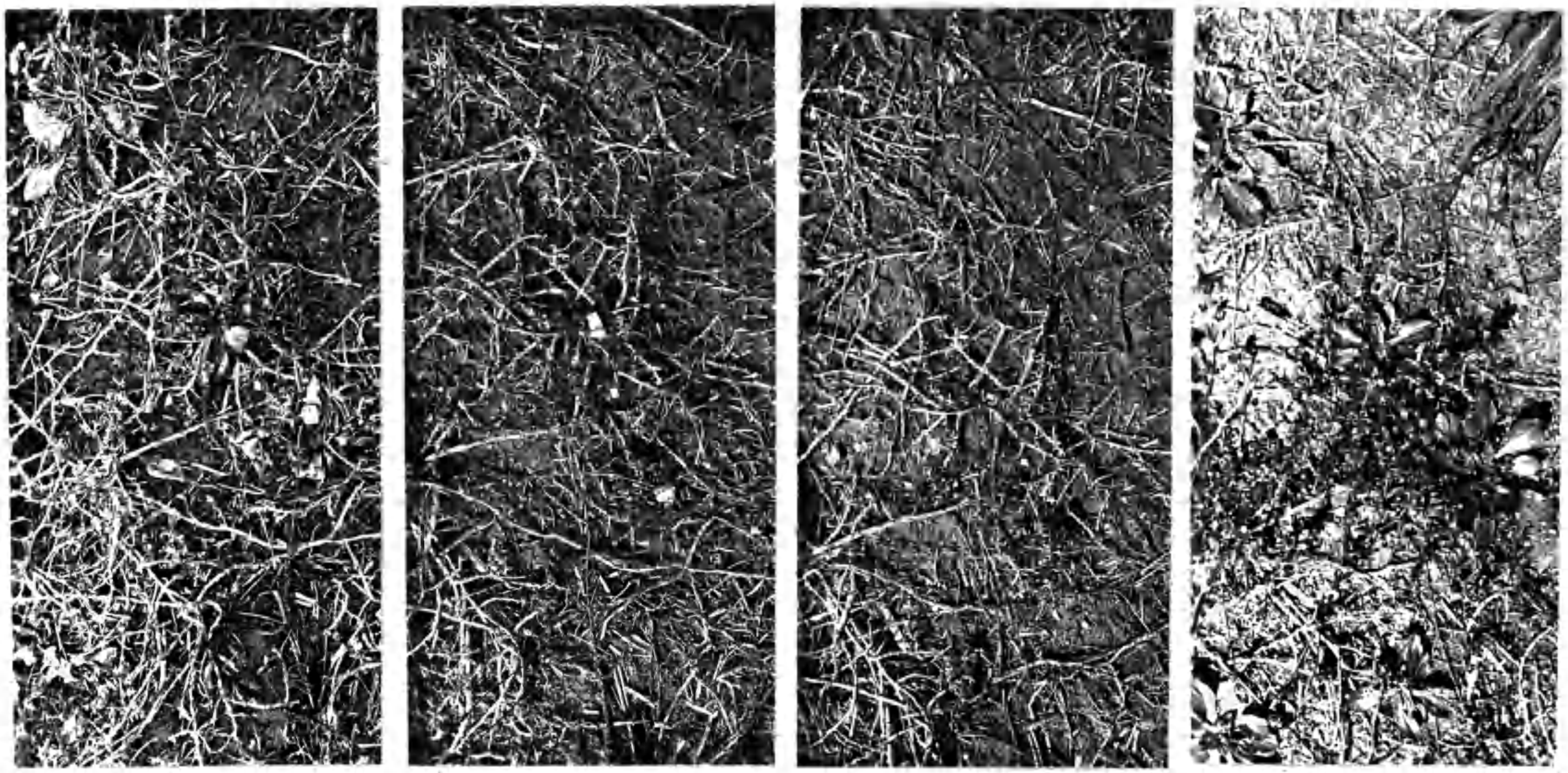
Figure 16. COMPARISON OF SOIL MOISTURE AT EIGHTEEN-INCH LEVEL IN TWO LADINO CLOVER PLOTS





January February March April

Figure 17. Survival following winter damage to ladino clover on a plot where only a limited amount of heaving occurred during the 1951-52 winter period.



January February March April

Figure 18. Survival following severe winter damage to ladino clover on a plot where considerable heaving occurred during the 1951-52 winter period

plants made considerably more fall growth. Because of this the soil surface was better protected from low temperatures and less winter heaving occurred. The first picture in Figures 17 and 18 was taken in the middle of January immediately following a period when rather severe heaving of ladino clover stolons and roots had occurred. The remaining views were taken at intervals of approximately one month. Each successive photograph covers exactly the same area in each plot. Complete elimination of ladino clover occurred in the badly heaved area which also had a less favorable soil moisture supply the previous summer, while a fair amount of clover survived at the other locations. The severity of heaving can be seen in Figure 19. This stolon was heaved so that between one and two inches of fresh roots were exposed to the cold, dry winter winds. The amount of desiccation and breakdown of the same roots and stolons that occurred over a month's time can be seen in the lower photograph.

Following severe heaving and desiccation several weeks of warm weather made conditions ideal for the destructive spread of Sclerotinia trifoliorum and other root and stolon rot organisms. This resulted in virtually a complete breakdown of the exposed tissue, as shown in the lower part of Figure 19. In contrast to these conditions the degree of winter survival in the 1950-51 season is shown in Figure 20. There were no test areas of ladino clover showing any more heaving or loss of stand than can be seen in this series of pictures. It should be pointed out that the fall growth in

Ladino clover stolon

Same stolon one month later

Figure 19. Heaving damage on ladino clover

A freshly heaved stolon and roots, with the same plant section shown one month later after exposed parts had been dried out and broken down.

January February March April

Figure 20. Winter survival and excellent spring growth of ladino clover for the 1950-51 season.

1950 was considerably greater and more uniformly distributed than on the same plots the following year when essentially no fall growth was made.

Precipitation for 1952 was about normal except for the months of March, April, May, August and November which were well above the long-time average for this area. September and October had very low rainfall with only 0.60 of an inch falling during the latter month. This emphasizes the well-known principle that distribution of rainfall may be as important as total amounts.

Temperatures for 1952 were slightly higher than those for the previous year as well as the long-time average. During several days in the latter part of June and first of July daily average temperatures of 100° F. were noted.

Temperature in Relation to Growth

Temperatures and their effects on the initiation and rate of early spring growth of several important perennial forage species were studied during the early spring months. The growth of Kentucky bluegrass and orchard grass in 1951 was started during the week ending March 5. The following spring, growth of orchard grass began approximately one week later while Kentucky bluegrass was two weeks later in starting its growth. The growth of ladino clover also began about one week later in 1952 than during the previous spring.

The effects of temperature on the initiation and rate of growth were studied by calculating temperature-growth indices for several soil and air levels within each of the species or mixture of species being considered. Formula (G) page 42 was used in calculating these indices. Soil surface temperatures appeared to be more closely associated with initiation and early spring growth rates of the several species than air temperatures. This does not seem unreasonable since a very large percentage of the root system of these grasses and legumes is located in the top few inches of soil. The reproductive portions of new stems and leaves are also located near the soil surface at this time of the year. Also the growth processes must start in the roots or stolons where the carbohydrate reserves are stored.

The temperature-growth indices for the soil surface of each species and mixture are presented in Tables 2,3,4, and 5, along with their accumulations. The accumulations were begun in the middle of February approximately two weeks before the initiation of growth of any of these species. This was done to take into account a possible time lag between temperature change and plant response. These indices are in reality a measure of the relative amount of heat units accumulated during each weekly period.

In studying the data it was observed that both the day and night temperatures were important in determining growth initiation and that both must be considered. The earlier time of growth initiation in 1951 appeared to be associated with higher night temperatures. However, in every case, the growth of the various species began only when the accumulated

Table 2. Temperature indices for soil surface of orchard grass plot. A base temperature of 40° F. was used for these calculations.

1951

Week ending		Day		Night		Total	
		Weekly Totals	Accumulations	Weekly Totals	Accumulations	Weekly Totals	Accumulations
2-12		0	0	0	0	0	0
19		44	44	1	1	45	45
26		146	190	60	61	206	251
3-5	1/	262	452	147	208	409	660
12		281	733	78	286	359	1019
19		148	881	17	303	165	1184
26		252	1133	66	369	318	1502
4-2		444	1577	217	586	661	2163
9		433	2010	164	750	597	2760
16		514	2524	225	975	739	3499
23		493	3017	213	1188	706	4205

1952

Week ending		Day		Night		Total	
		Weekly Totals	Accumulations	Weekly Totals	Accumulations	Weekly Totals	Accumulations
2-12		82	82	4	4	86	86
19		36	118	0	4	36	122
26		116	234	1	5	117	239
3-5		63	297	3	8	66	305
12	2/	177	474	39	47	216	521
19		217	691	27	74	244	765
26		619	1310	245	319	864	1629
4-2		687	1997	259	578	946	2575
9		645	2642	300	878	945	3520
16		739	3381	392	1270	1131	4651
23		1022	4403	584	1854	1606	6257

1/ Approximate date of growth initiation in 1951

2/ Approximate date of growth initiation in 1952

Table 3. Temperature indices for the soil surface in orchard grass-ladino clover plot. A base temperature of 40° F. was used for these calculations.

1951

Week ending	Day		Night		Total	
	Weekly Totals	Accumu-lations	Weekly Totals	Accumu-lations	Weekly Totals	Accumu-lations
2-12	0	0	0	0	0	0
19	103	103	14	14	117	117
26	161	264	64	78	225	343
3-5 1/	265	529	137	215	402	744
12 2/	296	825	116	331	412	1156
19	172	997	13	334	185	1341
26	244	1241	29	373	273	1614
4-2	487	1728	228	601	715	2329
9	452	2180	180	781	632	2961
16	379	2559	244	1025	623	3584
23	511	3070	238	1263	749	4333

1952

Week ending	Day Weekly Totals	Day Accumu-lations	Night Weekly Totals	Night Accumu-lations	Total Weekly Totals	Total Accumu-lations
2-12	92	92	4	4	96	96
19	39	131	0	4	39	135
26	144	275	1	5	145	280
3-5	65	209	2	7	67	347
12 3/	160	369	36	43	196	543
19 4/	186	555	28	71	214	757
26	613	1168	254	325	867	1624
4-2	668	1836	277	602	945	2569
9	661	2497	289	891	950	3519
16	821	3318	391	1282	1212	4731
23	1251	4569	641	1923	1892	6623

1/ Approximate date of growth initiation for orchard grass 1951

2/ Approximate date of growth initiation for ladino clover 1951

3/ Approximate date of growth initiation for orchard grass 1952

4/ Approximate date of growth initiation for ladino clover 1952

Table 4. Temperature indices for soil surface in ladino clover plot. A base temperature of 40° F. was used for these calculations.

1951

Week ending		Day – Weekly Totals	Day – Accumulations	Night – Weekly Totals	Night – Accumulations	Total – Weekly Totals	Total – Accumulations
2-12		4	4	0	0	4	4
19		155	159	30	30	185	189
26		181	340	69	99	250	439
3-5		294	634	142	241	436	875
12	1/	408	1042	52	293	460	1335
19		229	1271	11	304	240	1575
26		323	1594	63	367	386	1961
4-2		525	2119	221	588	746	2707
9		522	2641	161	749	683	3390
16		601	3242	185	934	786	4176
23		613	3855	204	1138	817	4993

1952

Week ending		Day – Weekly Totals	Day – Accumulations	Night – Weekly Totals	Night – Accumulations	Total – Weekly Totals	Total – Accumulations
2-12		136	136	4	4	140	140
19		55	191	0	4	55	195
26		167	358	1	5	168	365
3-5		68	426	5	10	73	436
12		189	615	40	50	229	665
19	2/	235	850	28	78	263	928
26		597	1447	217	295	814	1742
4-2		771	2218	250	545	1021	2763
9		718	2936	237	782	955	3718
16		894	3830	364	1146	1258	4976
23		1449	5279	614	1760	2063	7039

1/ Approximate date of growth initiation for ladino clover 1951

2/ Approximate date of growth initiation for ladino clover 1952

Table 5. Temperature indices at soil surface for Kentucky bluegrass. A base temperature of 40° F. was used for these calculations.

1951

Week ending		Day Weekly Totals	Day Accumulations	Night Weekly Totals	Night Accumulations	Total Weekly Totals	Total Accumulations
2-12		0		0		0	
19		52	52	8	8	60	60
26		120	172	91	99	211	271
3-5	1/	229	401	161	260	390	661
12		239	640	134	394	373	1034
19		105	745	27	421	132	1166
26		156	901	66	487	222	1388
4-2		352	1253	188	675	540	1928
9		330	1583	201	876	531	2459
16		439	2022	248	1124	687	3146
23		482	2504	253	1377	735	3881

1952

Week ending		Day Weekly Totals	Day Accumulations	Night Weekly Totals	Night Accumulations	Total Weekly Totals	Total Accumulations
2-12		91	91	10	10	101	101
19		40	131	1	11	41	142
26		118	249	5	16	123	265
3-5		50	299	7	23	57	322
12		143	442	45	68	188	510
19	2/	204	646	52	120	256	766
26		563	1209	284	404	847	1613
4-2		635	1844	326	730	961	2574
9		648	2492	377	1107	1025	3599
16		736	3228	442	1549	1178	4777
23		1082	4310	627	2176	1709	6486

1/ Approximate date of growth initiation for Kentucky bluegrass 1951

2/ Approximate date of growth initiation for Kentucky bluegrass 1952 day temperatures reached an apparently "critical" range. In 1952 high temperatures that occurred during the last week of January and the first week of February appeared to be too early and/or to be of too short a duration to effect initiation of spring growth.

Even though there was a difference of a week between the time orchard grass started growth in the two years, the difference in accumulation of heat units for the daylight hours was essentially the same. These values were 452 in 1951 and 474 the following year, a difference of only 22 units. When grown with ladino clover these values were 529 and 500, respectively, with a difference of only 29 units. The slightly lower values for orchard grass grown alone indicates that plants are better able to take advantage of the increasing temperature with a more readily available nitrogen supply, since these plots were top dressed with ammonium nitrate, while the legume supplied the nitrogen for the grass-legume mixture. The growth differential brought about by this difference in nitrogen supply and availability was maintained throughout the early spring growth period. This is in agreement with the work reported by Blackman (9) who found essentially no growth of several forage grasses when the soil temperature at four inches was below 42° F. Between 42° F. and 47° F. the application of nitrogen greatly increased the growth rate over the plots where nitrogen was not applied.

The differences in night temperatures between the two years were large compared to the small differences in day temperatures. Even though these differences were large the total heat unit accumulation for the day plus night was very close. The first year 660 units were accumulated before growth initiation of orchard grass grown alone and top dressed with nitrogen, while 744 units were accumulated when grown with ladino without supplying additional nitrogen. The following year these values were 521 and 543, respectively. These differences seemed to be reflected in the behavior of the plants during these two spring seasons. The first year growth was initiated somewhat earlier apparently due to the higher night temperatures. The following year the day temperatures were equally warm, but the night temperatures were colder. This was associated with the later growth initiation but a slightly higher growth rate once growth started. This higher growth rate the second year also seemed to be associated with a steady increase in temperature, whereas the previous spring growth was initiated and then retarded by a week of cold weather. The plants never seemed to completely recover from this temporary setback. Blackman (9) found that the greatest "degree of earliness" was obtained in those years when the four-inch soil temperature (at 9:00 a.m.) increased more slowly from 42° to 47° F. and when the temperature was between 42° and 44° F. for a considerable portion of that period.

In the case of Kentucky bluegrass the results were essentially the same as those found for orchard grass with a total of 661 units accumulated in 1951 and 766 the following year. There is a difference of only 105 units even though a difference of two weeks occurred in date of growth initiation. However, when broken down into day and night values the relationship was not as good. This can be accounted for in part by the fact that the Kentucky bluegrass sod had considerably more growth in the fall of 1950 than in 1951. This heavier growth served as an insulating layer resulting in cooler day temperatures and warmer night temperatures at the soil surface than occurred in 1952. Furthermore, growth measurements of the longer leaves of orchard grass are more easily and perhaps more accurately made than growth measurements of the smaller leaves of Kentucky bluegrass.

Once growth had started each increased increment of temperature resulted in a corresponding increase in growth. The weekly growth rates of the various species are shown in Figures 21 and 22. The accumulated growth of each is given in Figures 23 and 24.

During both seasons the growth of orchard grass grown alone and top dressed with 150 pounds of nitrogen per acre was considerably more than when grown with ladino clover and not top dressed. As stated earlier the more uniform growth in 1952 appeared to be closely associated with a steady increase in temperature. In 1951, the third week after growth began was quite cool. This caused a reduction in the

Figure 21. WEEKLY GROWTH RATES OF ORCHARD GRASS AND LADINO CLOVER GROWN ALONE AND IN ASSOCIATION

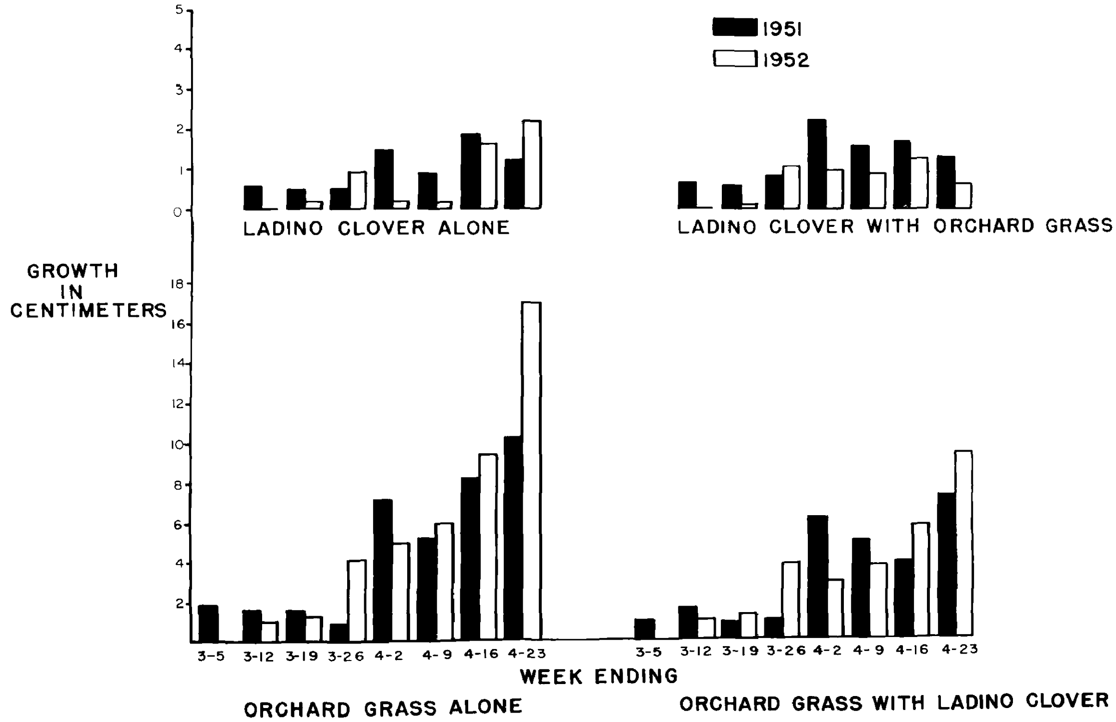


Figure 22. WEEKLY GROWTH RATES OF ALFALFA, BLUEGRASS AND BROMEGRASS

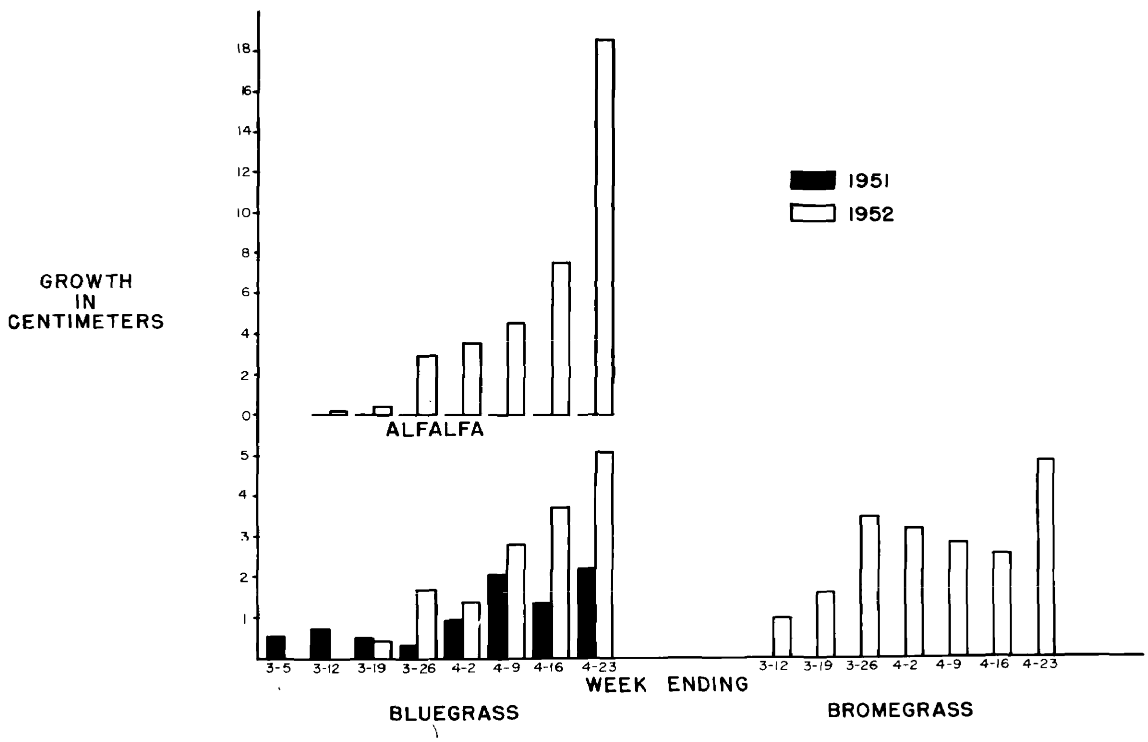


Figure 23. ACCUMULATED SPRING GROWTH OF ORCHARD GRASS AND ALFALFA

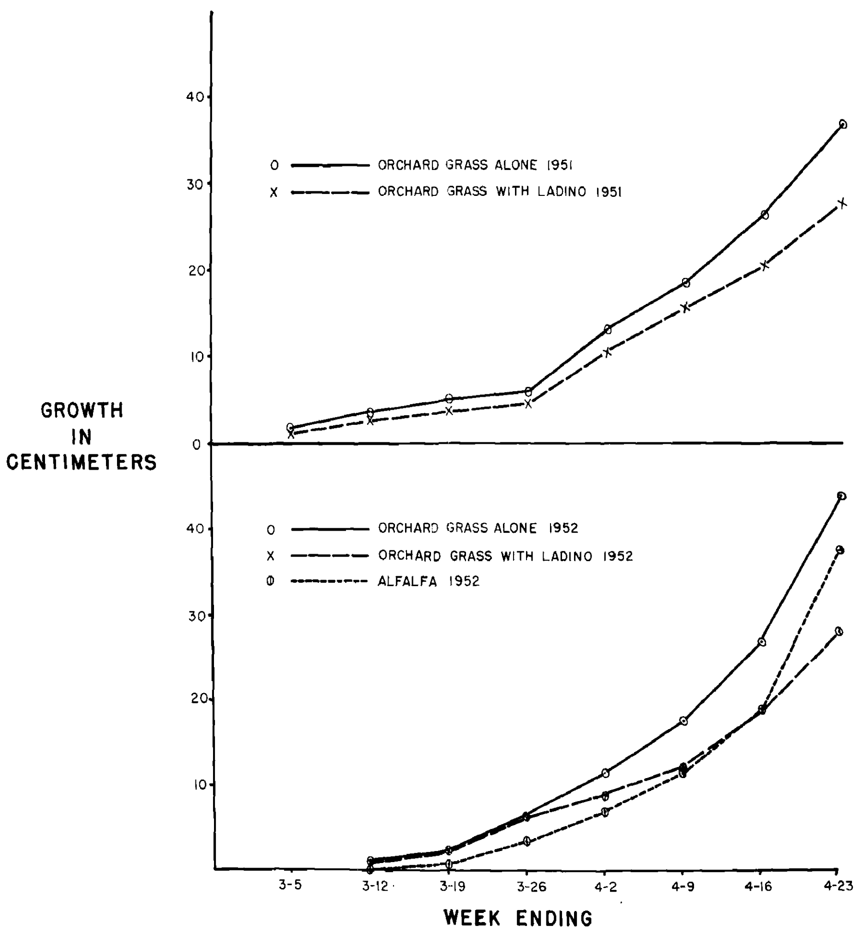
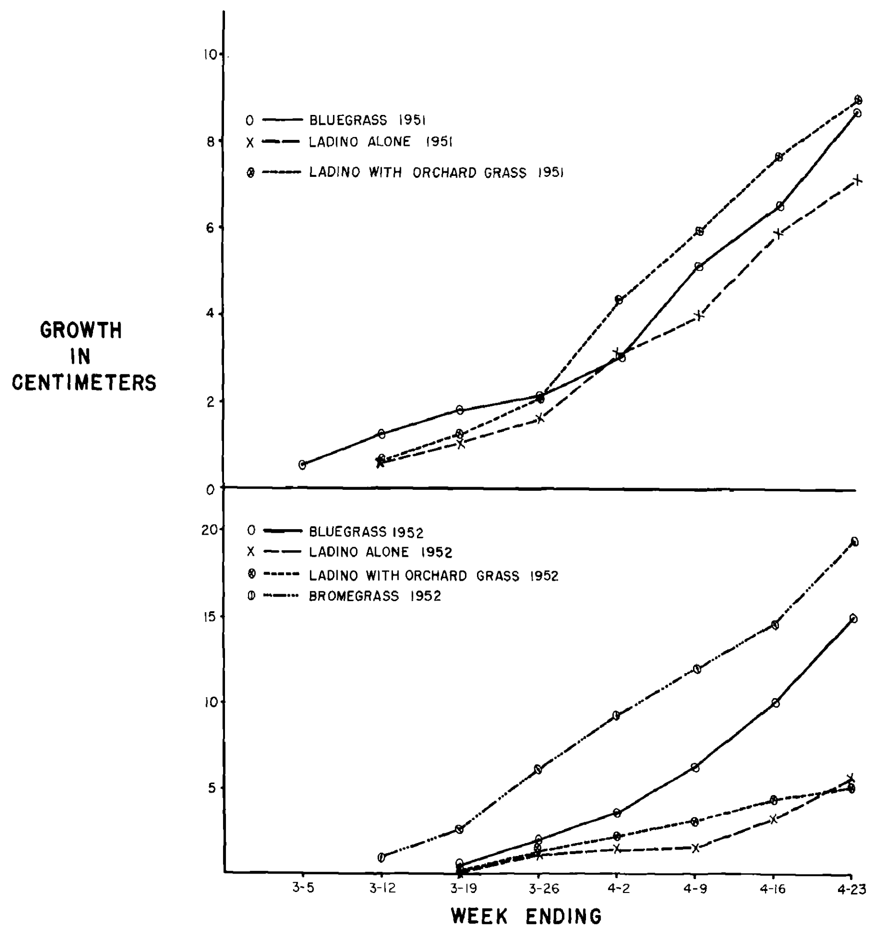


Figure 24. ACCUMULATED SPRING GROWTH OF BLUEGRASS, BROMEGRASS AND LADINO CLOVER



growth rates of each species. This temporary setback appeared to be carried throughout the next two months at which time the leaf elongation measurements were discontinued.

Periodic photographs were taken of each plot to have a pictorial record of the growth of the species being studied. The same portion of each plot was photographed each time and the camera was set at the same height and angle in every instance. Both black and white and colored photographs were taken. The growth of orchard grass and ladino clover is shown in Figures 25 and 26. The first picture was taken during the week growth began and the last one the week growth measurements were discontinued. The same series for alfalfa and bromegrass is shown in Figures 27 and 28. The Kentucky bluegrass plot was clipped each week after the leaf elongations were made; therefore photographs would not be effective in showing growth rates of this species. These weekly clippings were saved in 1952 and the weekly yields of oven-dry material were correlated with the respective amounts of leaf elongation during the same week. A correlation coefficient of 0.938 was obtained which was significant at the .05 level. The growth rate of Kentucky bluegrass was not as great nor as uniform as in the case of orchard grass, but the same general growth patterns were obtained. The temperature indices for growth were very nearly the same in all cases.

Growth rates of ladino clover during both years was somewhat erratic and much less uniform than with the grasses and alfalfa. This was partly due to the extreme difficulty in

Figure 25. Pictorial presentation of spring growth made by orchard grass and ladino clover in 1951.

The first photograph was taken the first week of March and each succeeding one approximately one week later.

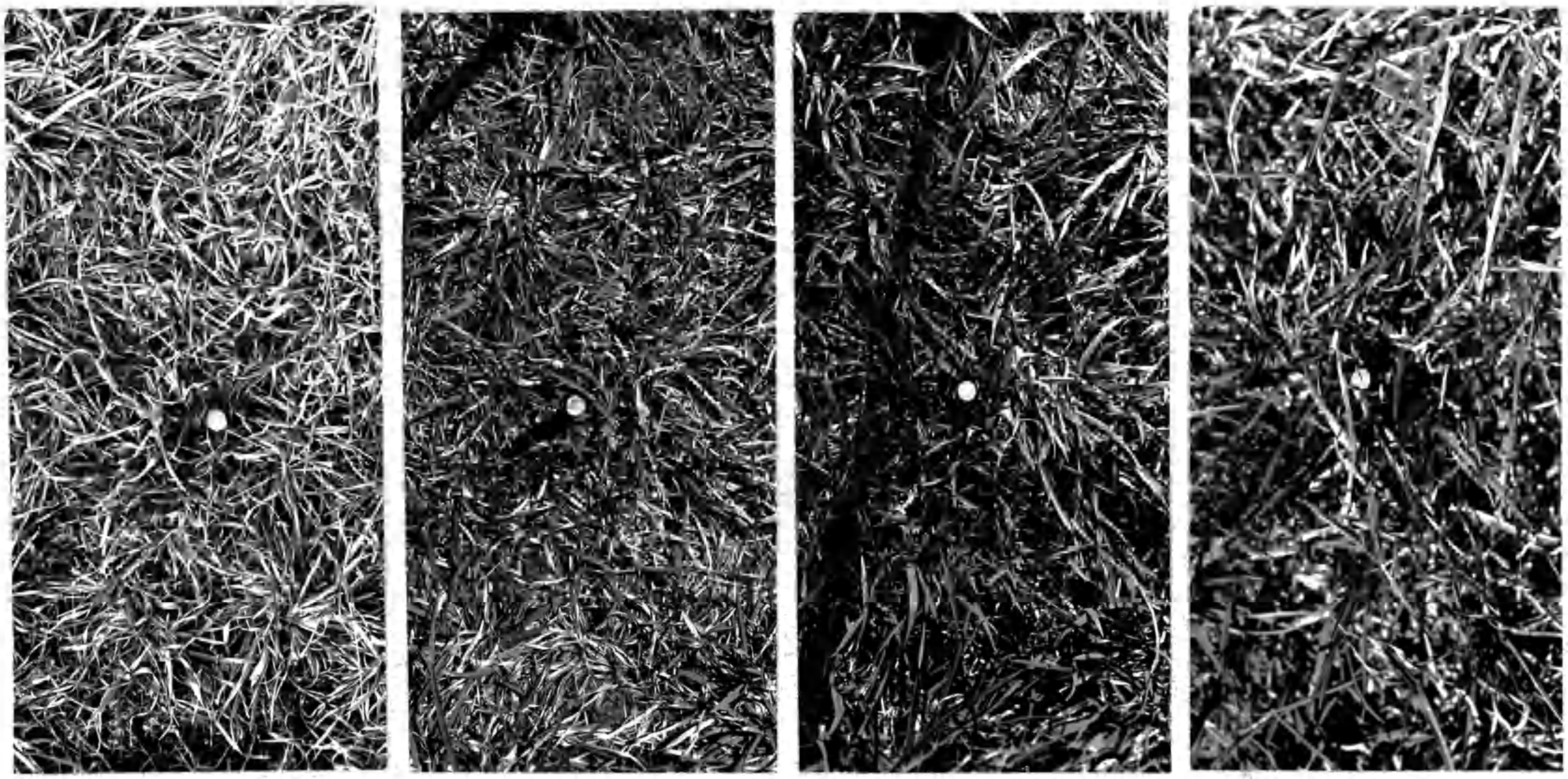


Figure 26. Pictorial presentation of spring growth made by orchard grass and ladino clover in 1952.

First photograph was taken during the first week of growth and each succeeding one approximately one week later.

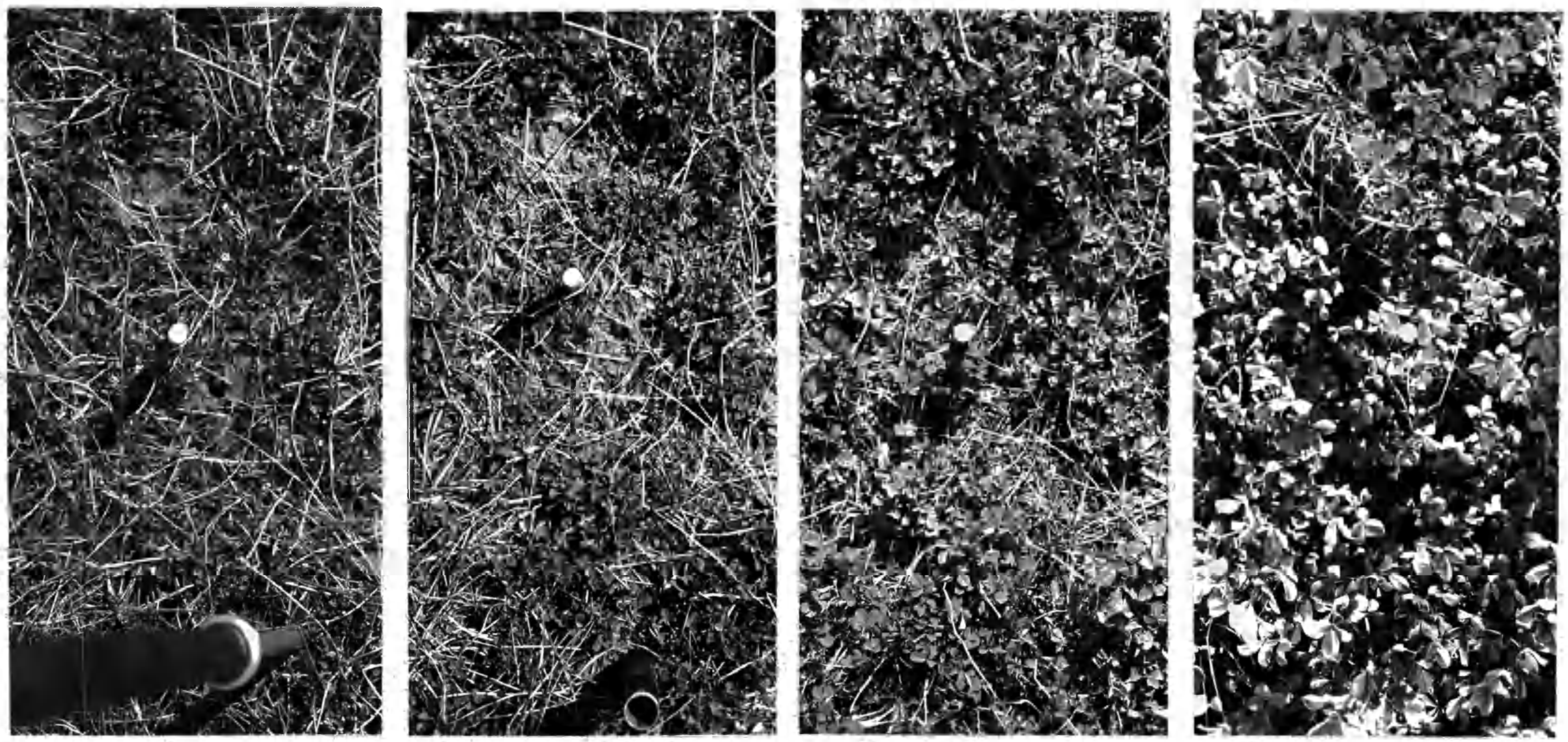


Figure 27. Pictorial presentation of spring growth made by alfalfa in 1952.

The first photograph was taken during the first week of growth and each succeeding one approximately one week later.

Figure 28. Pictorial presentation of spring growth of bromegrass-ladino clover in 1952.

The first photograph was taken during the first week of growth and each succeeding one approximately one week later.

making accurate leaf elongation measurements in the field without injuring the ladino clover petiole and partly due to the nature of the growth pattern in the early stages. Drought conditions in the summer of 1951 followed by adverse winter conditions and a heavy infestation of such root organisms as Sclerotinia trifoliorum in the spring resulted in complete elimination of many ladino clover plants. This partially accounted for the erratic growth pattern.

Correlation coefficients between growth rates of these species and various methods of expressing temperatures are presented in Tables 6 and 7. The first and most obvious characteristic was the great similarity between all methods. For instance, if one method gave a high correlation coefficient they were all high. The next outstanding characteristic was that all of the coefficients for 1952 were larger than those for 1951, except in the case of ladino clover. This poor relationship was, of course, mainly due to the very erratic and weak growth of the badly heaved and diseased ladino clover plants. These facts were rather startling at first but a little study on the problem helped to explain some of the reasons. First, one would expect to find a very high correlation between soil and air temperatures since the air temperatures are a result of soil temperatures. Short wave radiations from the sun are absorbed by the soil and other objects on the ground or in the air and reradiated as longer heat waves, thereby warming up the surrounding atmosphere. Long wave radiation may also be reflected back to the earth by

Table 6. Correlations of leaf elongation with 60-inch air temperatures using four methods of calculating temperature values.

		Daily Average Temp.		Temperature Indices					
				Modified Livingston formula			Frequency Distribution		
Type of Cover	Year	Max-Min. Ave.	Two-hour record Ave.	Day	Night	Total	Day	Night	Total
Orchard Grass	1951	.741	.844	.863	.633	.863	.836	.643	.802
	1952	.945*	.966*	.961*	.964*	.967*	.963*	.966*	.965*
Orchard Grass 1/	1951	.817	.889	.910*	.630	.894	.856	.667	.827
	1952	.960*	.967*	.962*	.977*	.974*	.964*	.965*	.965*
Ladino Clover	1951	.788	.853	.889	.866	.883	.897	.764	.877
	1952	.825	.819	.817	.867	.838	.816	.840	.824
Ladino Clover 2/	1951	.963*	.939*	.903	.905	.909	.889	.865	.903
	1952	.278	.257	.147	.320	.204	.219	.200	.198
Blue-grass	1951	.621	.677	.740	.640	.734	.661	.281	.542
	1952	.878	.908	.866	.932*	.893	.879	.878	.880
Alfalfa	1952	.946*	.959*	.967*	.950*	.968*	.965*	.977*	.970*
Brome-grass	1952	.946*	.930*	.938*	.927*	.934*	.931*	.901	.922*

1/ Orchard grass grown with ladino clover

2/ Ladino clover grown with orchard grass

* Significant at $P_{.01}$ level

Table 7. Correlations of leaf elongation and soil surface temperatures using four methods of calculating temperature values.

Type of Cover	Year	Daily Average Temp.: Max-Min Ave.	Daily Average Temp.: Two-hour record Ave.	Temperature Indices: Modified Livingston formula: Day	Modified Livingston formula: Night	Modified Livingston formula: Total	Frequency Distribution: Day	Frequency Distribution: Night	Frequency Distribution: Total
Orchard Grass	1951	.933	.918*	.911*	.654	.823	.909	.871	.914
	1952	.627	.902	.855	.857	.858	.900	.963*	.931*
Orchard Grass 1/	1951	.945	.956*	.927*	.644	.828	.965	.810	.954*
	1952	.949	.950*	.943*	.900	.929*	.963*	.977*	.968*
Ladino Clover	1951	.711	.806	.884	.859	.873	.929*	.943*	.943*
	1952	.944	.829	.821	.795	.819	.807	.866	.828
Ladino Clover 2/	1951	.832	.853	.743	.734	.766	.807	.752	.830
	1952	.444	.455	.423	.583	.486	.407	.375	.397
Ky. Blue-Grass	1951	.834	.857	.886	.586	.789	.816	.785	.811
	1952	.932	.957*	.914	.881	.905	.929*	.953*	.951*
Alfalfa	1952	.813	.925*	.774	.792	.785	.842	.925*	.882
Brome-grass	1952	.939	.939*	.946*	.910	.938*	.936*	.897	.913*

1/ Orchard grass grown with ladino clover

2/ Ladino clover grown with orchard grass

* Significant at $P_{.01}$ level

clouds, etc. The higher correlations obtained with the air temperature in contrast to the soil temperatures can be partially explained as follows. Higher correlations are obtained using the soil temperature while the vegetation was relatively short but after the crop plants began shading the soil the air temperatures became more and more important. This shading effect was rather large in the case of orchard grass.

The data in Table 8 indicate the extent to which the various soil and air temperatures are related. There is nearly a perfect correlation between soil surface temperatures and those noted three inches below the soil surface. The correlation was somewhat lower between the soil surface and the air temperatures at 3, 12, and 60 inches above the soil surface. The poorest relationship was found at the three-inch height over a Kentucky bluegrass sod uniformly clipped at two inches. The values obtained at the 12-inch level were slightly higher, with the highest values for all species being obtained at the 60-inch height.

Generally speaking the day temperatures gave a slightly higher correlation value with growth than did the night temperatures. This was particularly true the first year. The poorest correlations were obtained between growth rates and the three-inch air temperatures. This was to be expected since it is in this region that the greatest extremes in temperature occur.

Table 8. Correlations of soil surface temperature indices with air temperature indices.

Type of Cover	Year	Level of Measurement: Three inches below soil surface			Three inches above soil surface			Twelve inches above soil surface			Sixty inches above soil surface		
		Day	Night	Total	Day	Night	Total	Day	Night	Total	Day	Night	Total
Orchard-Ladino	1951				.920*	.483	.940*	.895	.795	.934*	.905	.825	.941*
	1952	.999*	.978*	.998*							.978*	.967*	.975*
Orchard Grass	1951				.901*	.495	.878	.959*	.592	.894	.933*	.888	.943*
	1952	.999*	.916*	.987*							.948*	.948*	.952*
Ky. Blue-grass	1951				.829	.132	.760	.921*	.532	.860	.895	.779	.902
	1952	.999*	.999*	.999*	.951*	.938*	.974*	.954*	.942*	.953*	.957*	.926*	.953*
Ladino Clover	1951				.957*	.721	.935*	.932*	.825	.926*	.890	.911*	.871
	1952	.998*	.996*	.998*							.982*	.976*	.980*
Alfalfa	1952	.996*	.996*	.999*							.946*	.950*	.952*
Bare-ground	1952	.997*	.993*	.997*							.986*	.981*	.732

* Significant at $P_{.01}$ level

Growth rates of the various forage species being studied were plotted against the temperature-growth indices. These data are presented in Figures 29 to 40 inclusive. In these figures the weekly growth rates of each species were plotted against weekly temperature indices. In addition these same data were accumulated throughout the period of study so that a comparison of the two systems could be made for the two years.

When the growth rates of orchard grass were handled in this manner, a close relationship was found between plant growth rates and calculated temperature indices, as shown in Figure 29. This was true during both seasons with the higher temperature indices obtained in 1952 being associated with the higher growth rates for that spring. The points for each year were located in about the same area for the early period of growth, but after this initial period each year was characterized by a different type of curve depending upon the temperature situation. The growth rate tended to increase with each increment of heat units. The larger and faster growth rates for 1952 appeared to be associated with the fact that once temperatures began to rise they continued to do so, thereby avoiding injury to young succulent growth by sudden drops in temperature as occurred in 1951. Notice how the points for 1951 are more widely scattered during the first three weeks. The temperature-growth relationship is even better when these data are accumulated. This is shown in Figure 30 where the points are not scattered in the early part of the season but form essentially a straight line. This

Figure 29. WEEKLY GROWTH AND TEMPERATURE INDEX FOR ORCHARDGRASS ALONE

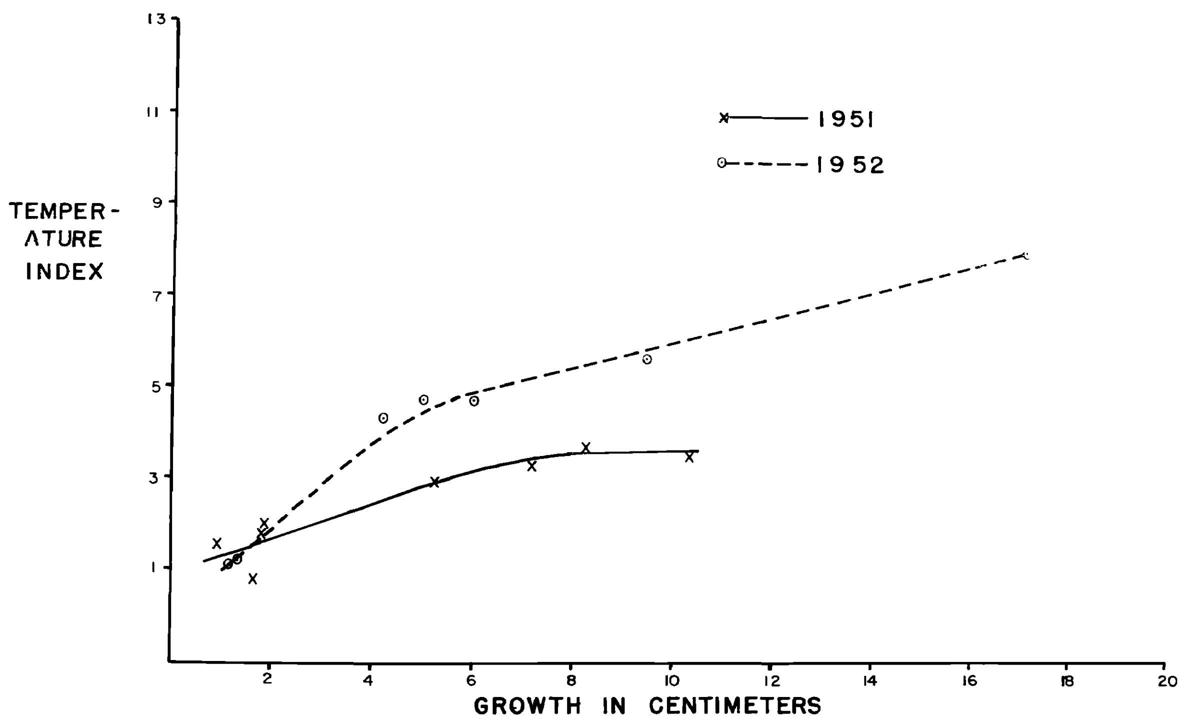
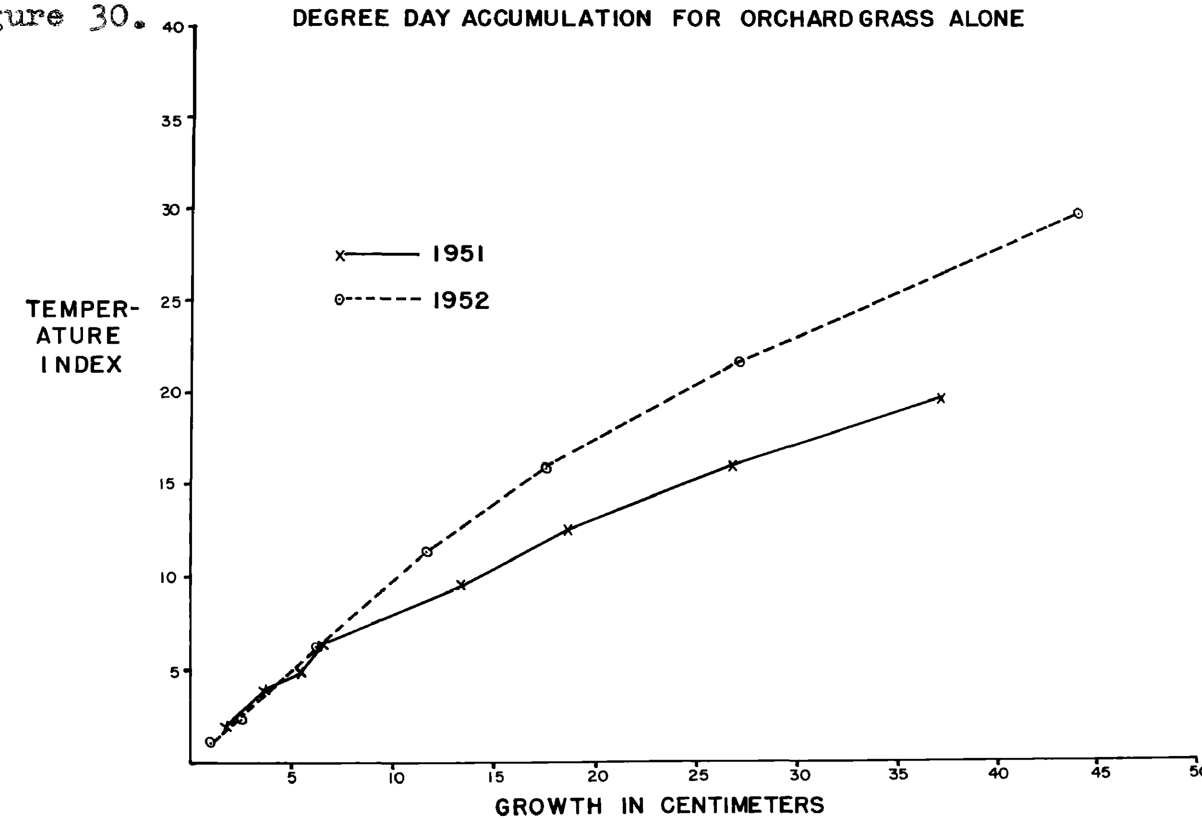


Figure 30. DEGREE DAY ACCUMULATION FOR ORCHARDGRASS ALONE



was true for both years with the difference between years still being maintained. The strong relationship between temperature and growth for this time of year suggests that growth rates could be rather accurately predicted from such data.

The same general growth pattern occurred when orchard grass was grown with ladino clover, Figure 31. The main difference was that the early growth of orchard grass was less when grown with ladino clover than when grown alone and top dressed with nitrogen. This lower growth rate produced a more flattened temperature-growth curve. When the data were accumulated as before, the type of curve shown in Figure 32 was obtained. Here as before the accumulation of these data tended to smooth out the small variations that occurred with the result that a nearly straight-line relationship was obtained. Whether grown alone or with ladino clover the growth rates were about the same for both years. This was true until the temperature index reached a relative value between 6 and 7 units. From this point on the growth rates were greater for the second year.

The growth of bluegrass was somewhat more erratic especially during the first year. However, good agreement was obtained between growth and temperature indices. These data are presented in Figure 33. In the case of bluegrass, as with orchard grass, growth rates were much smaller for the 1951 season. This large difference in growth rates appeared to be more closely associated with temperature than with any

Figure 31. WEEKLY GROWTH AND TEMPERATURE INDEX FOR ORCHARDGRASS WITH LADINO

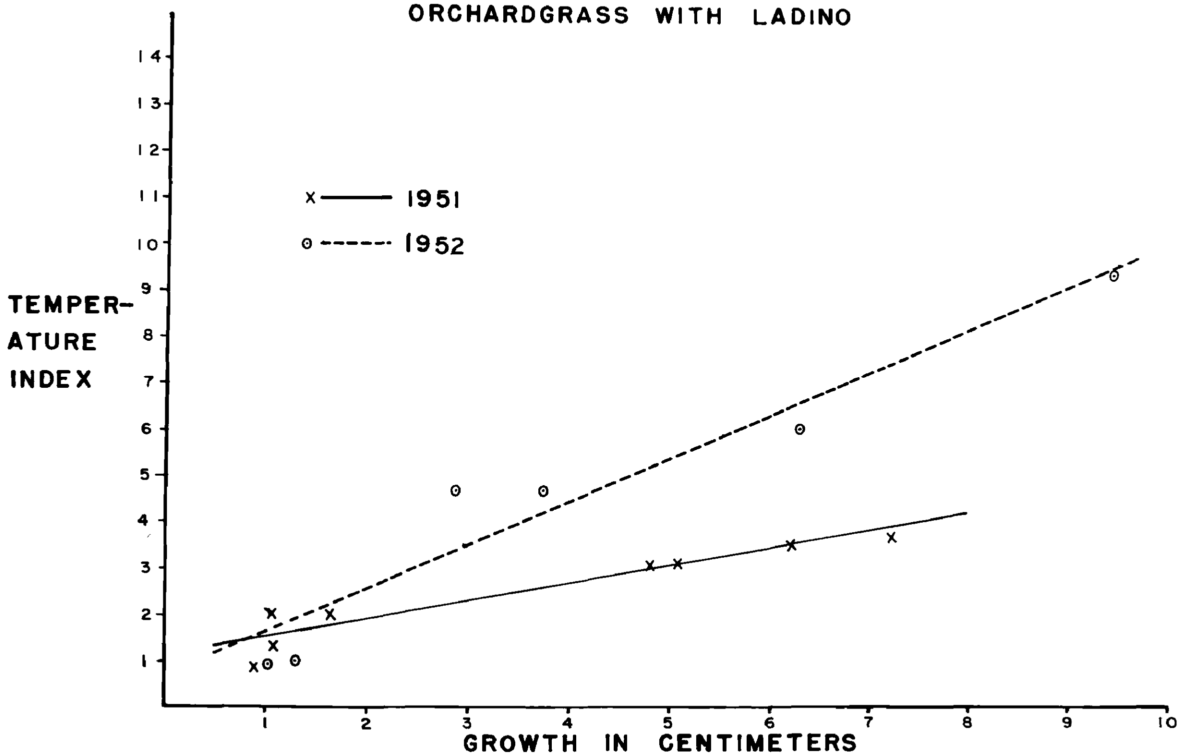
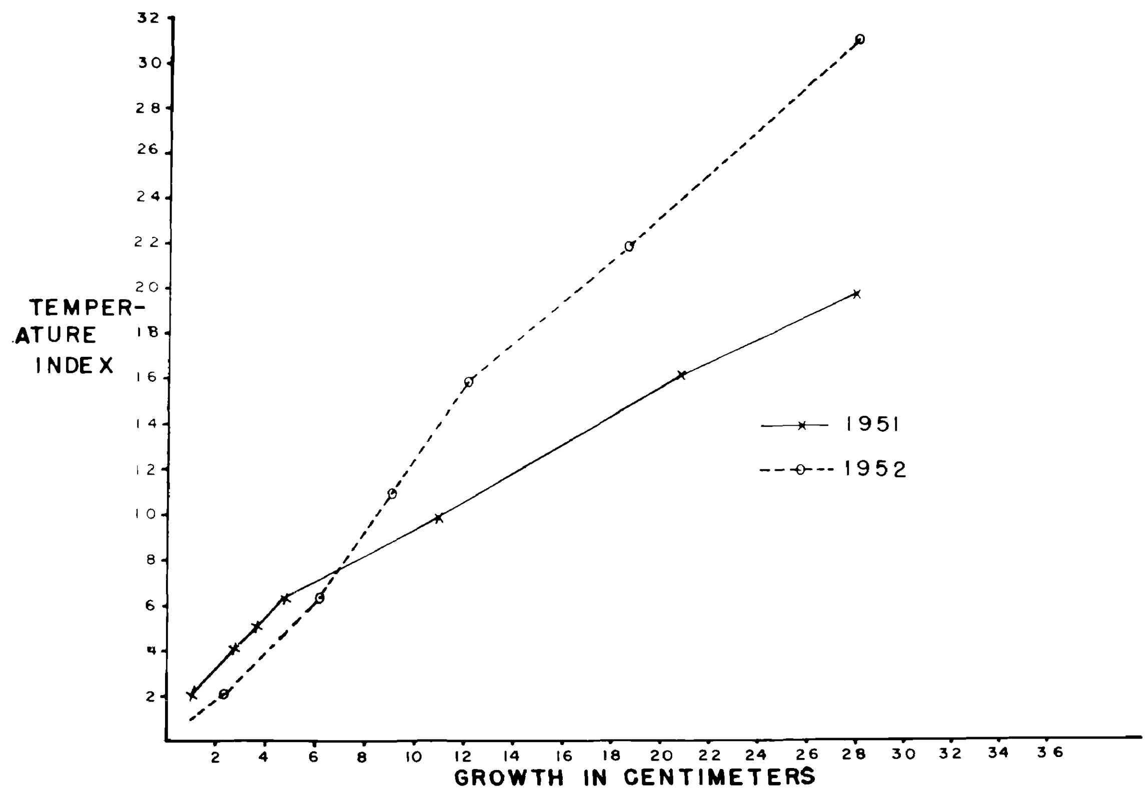


Figure 32. DEGREE DAY ACCUMULATION FOR ORCHARDGRASS WITH LADINO



other environmental factor. Good agreement was obtained when these data were accumulated, as shown in Figure 34. The differences that existed between years in the case of orchard grass were not present with bluegrass. All points fell essentially on the same line for the two years. The differences between the weekly presentation and the degree-day accumulations were even greater than those found with orchard grass. Not only did the accumulations cause the points for the single season to be more nearly in a straight line, but it also tended to minimize the differences between years.

Data for the growth rates of alfalfa and bromegrass were collected for only one year. They are presented in Figures 35 and 36. The growth rates of alfalfa were much more uniform throughout the study than were the growth rates for bromegrass. The relatively small amount of growth of bromegrass can be accounted for, in part, by the fact that nearly all of the ladino clover in this area had been lost during the previous winter thereby reducing the nitrogen supply for the grass. With relation to temperature, the growth rates of bromegrass tended to fall somewhat at random but still showed a weak but positive correlation. However, when these data were accumulated in Figure 36 a much better relationship was obtained. The general growth curve for alfalfa did not change greatly when the data were accumulated. The point that should be emphasized here, however, is that, in general, good agreement was obtained between growth and temperature indices

Figure 33. WEEKLY GROWTH AND TEMPERATURE INDEX FOR BLUEGRASS

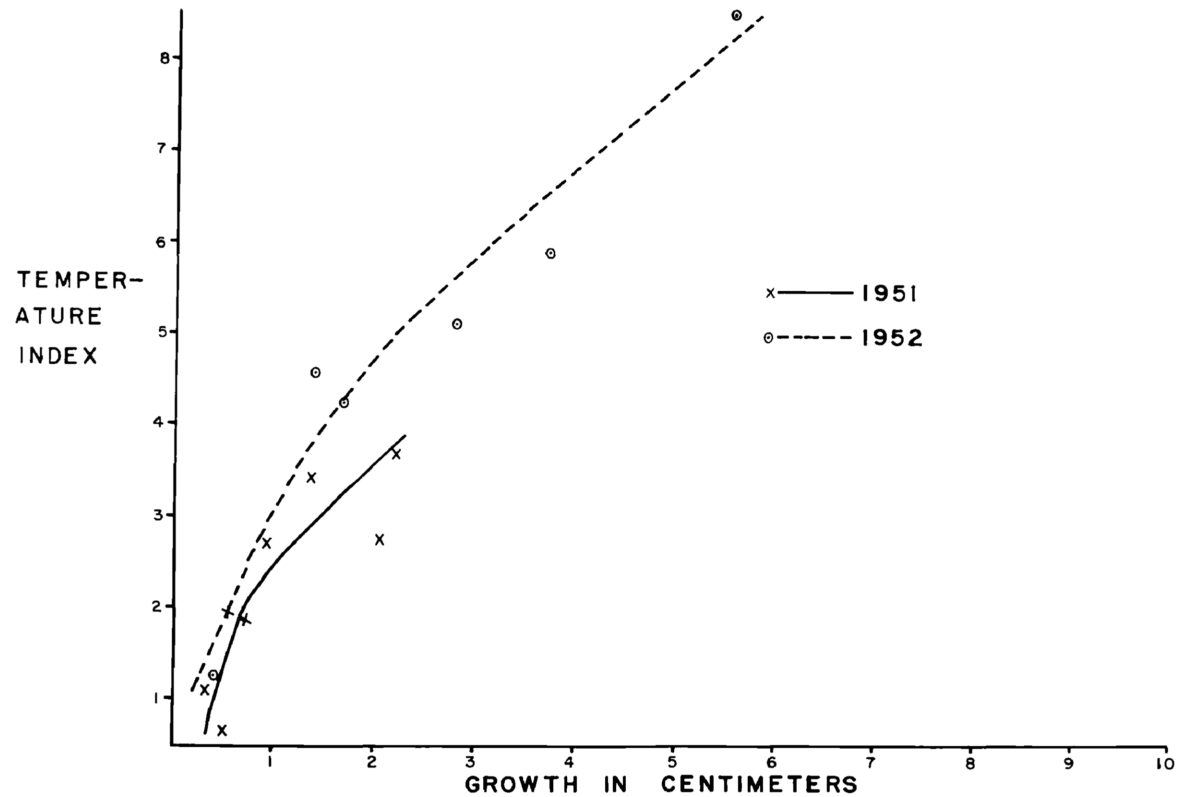


Figure 34. DEGREE DAY ACCUMULATION FOR BLUEGRASS

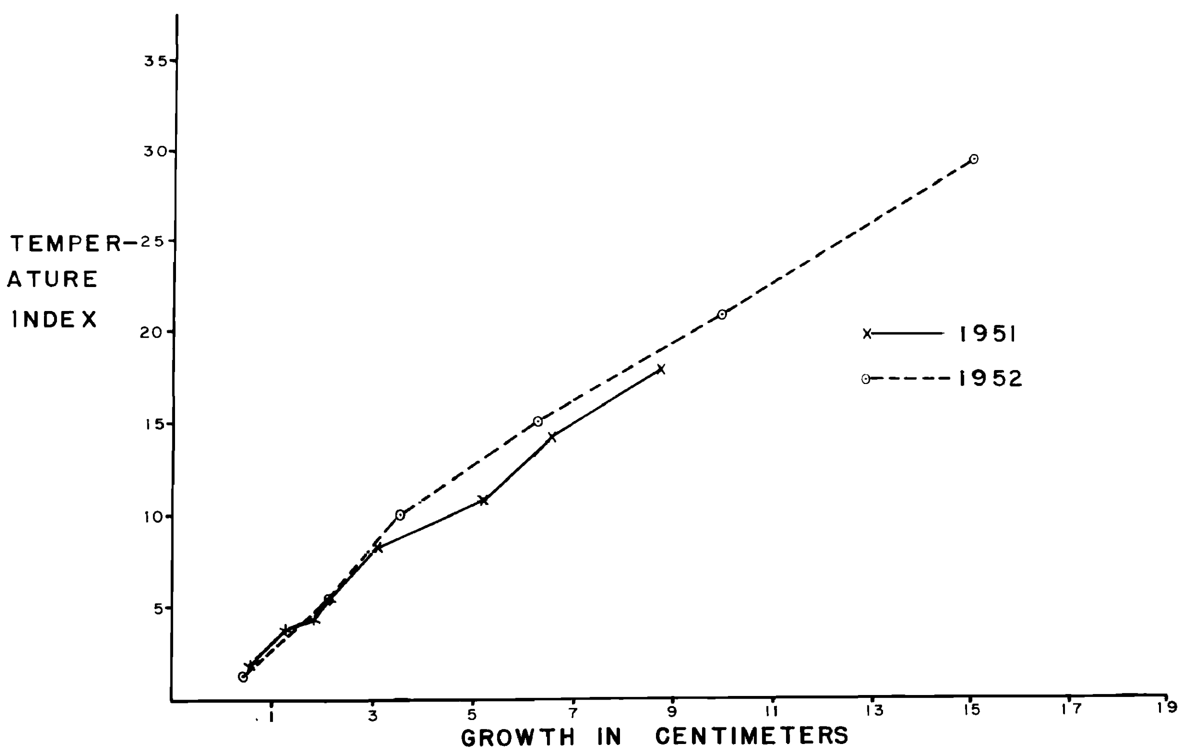


Figure 35. WEEKLY GROWTH AND TEMPERATURE INDEX FOR BROMEGRASS AND ALFALFA

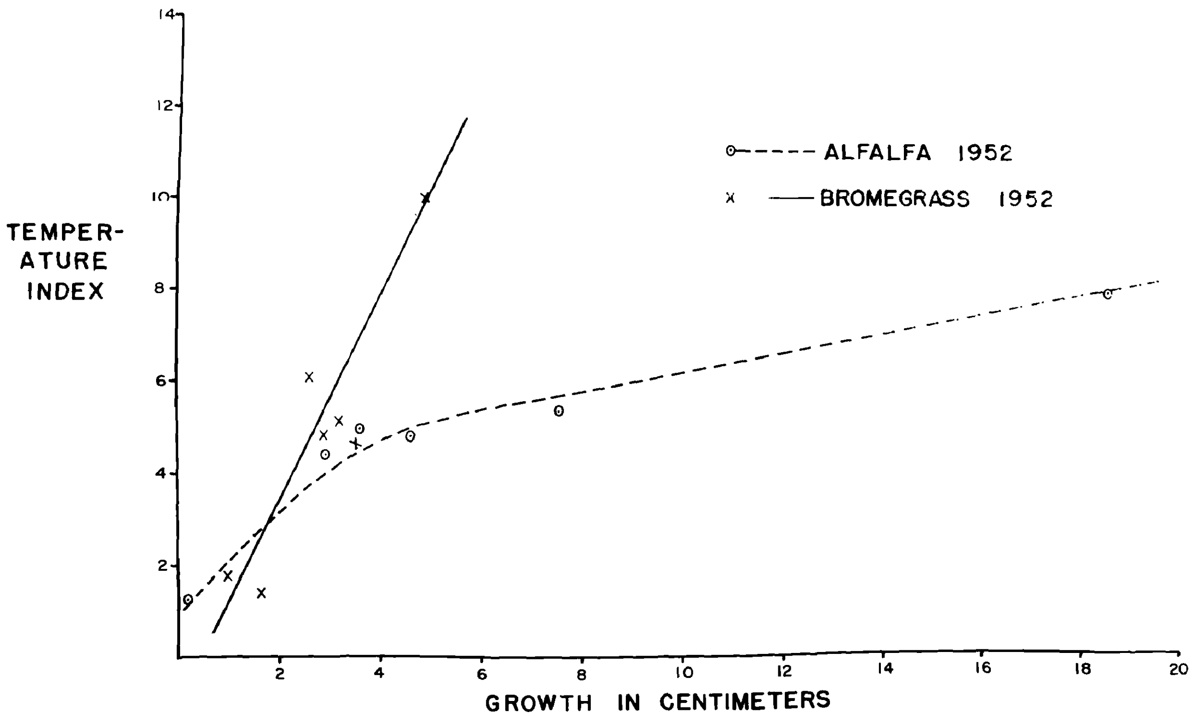
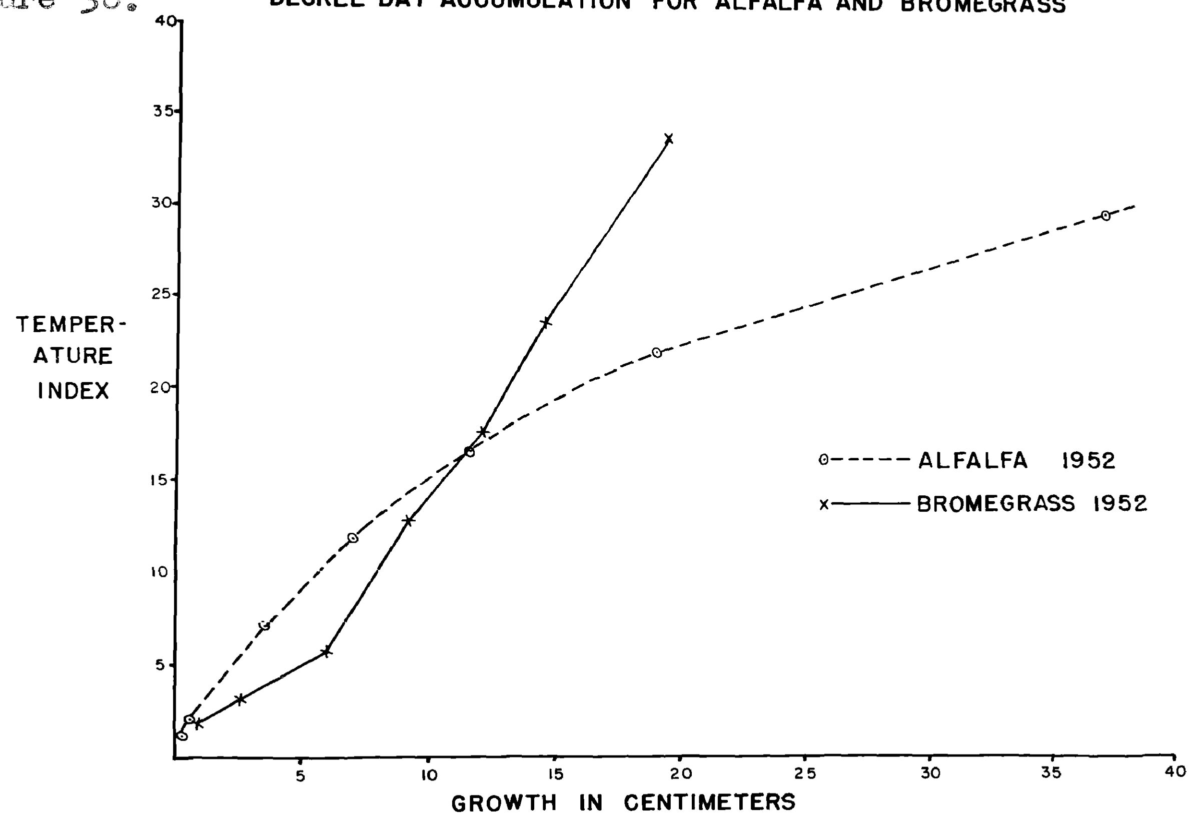


Figure 36. DEGREE DAY ACCUMULATION FOR ALFALFA AND BROMEGRASS



whether they were accumulated or whether they were handled on a weekly basis. This was not true with all of the data, as will be pointed out later.

The differences between weekly presentation of the growth data and the degree-day accumulation of these same data were much greater for ladino clover than for any of the other species. The growth curve for 1951, which is shown in Figure 37, was very similar to the growth curves of the other species. However, the data for 1952 was quite different. In this case the points seemed to fall at random with only a very slight positive trend. When these same data were accumulated as shown in Figure 38 the result was essentially a straight-line relationship. These differences were even greater when the data, shown in Figures 39 and 40, for the orchard grass and ladino clover plots were considered. In this case the weekly values, when plotted, produced a random distribution of the points. This was especially true for the 1952 values. This was what should be expected since the actual growth of individual plants was very erratic especially during the second spring. However, when these data were accumulated an excellent relationship seemed evident between growth and temperature indices. These degree-day data gave straight-line relationships for both years regardless of the true situation.

It seemed obvious that the degree-day accumulations were rather hazardous to use in relating temperature and growth. In these instances very good agreement was obtained

Figure 37. WEEKLY GROWTH AND TEMPERATURE INDEX FOR LADINO ALONE

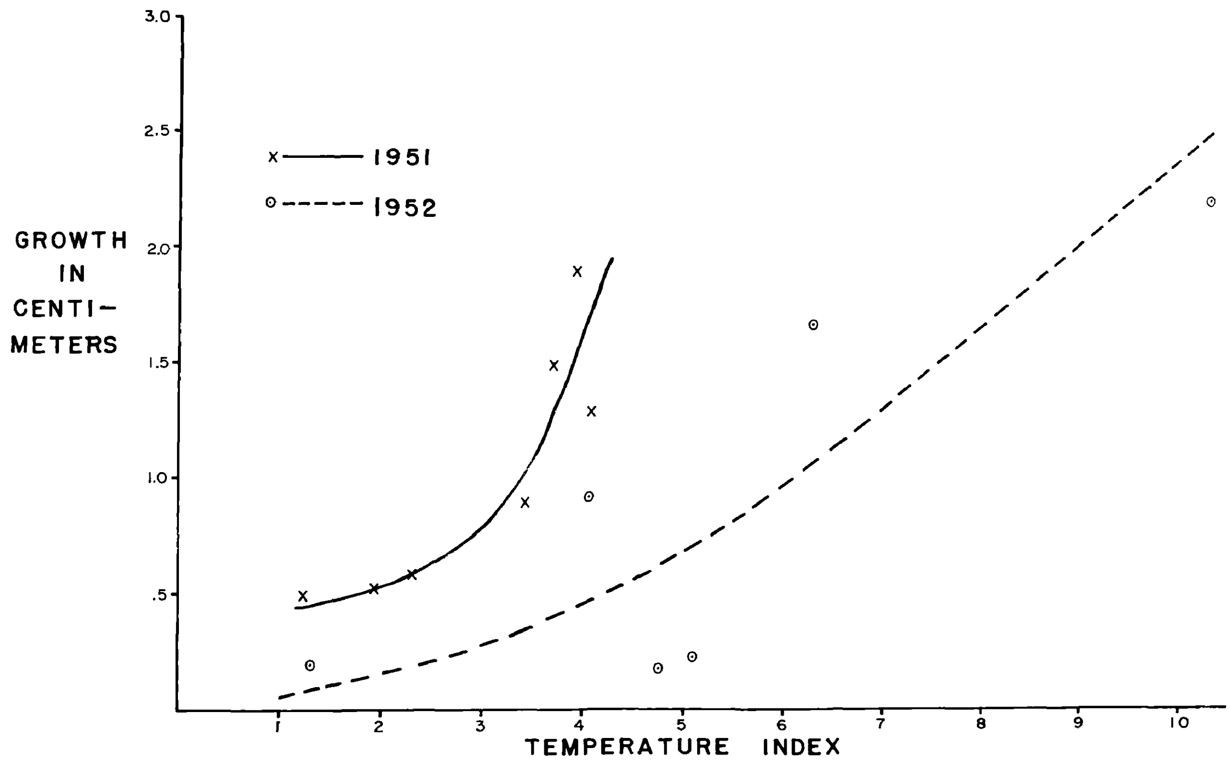


Figure 38. DEGREE DAY ACCUMULATION FOR LADINO CLOVER ALONE

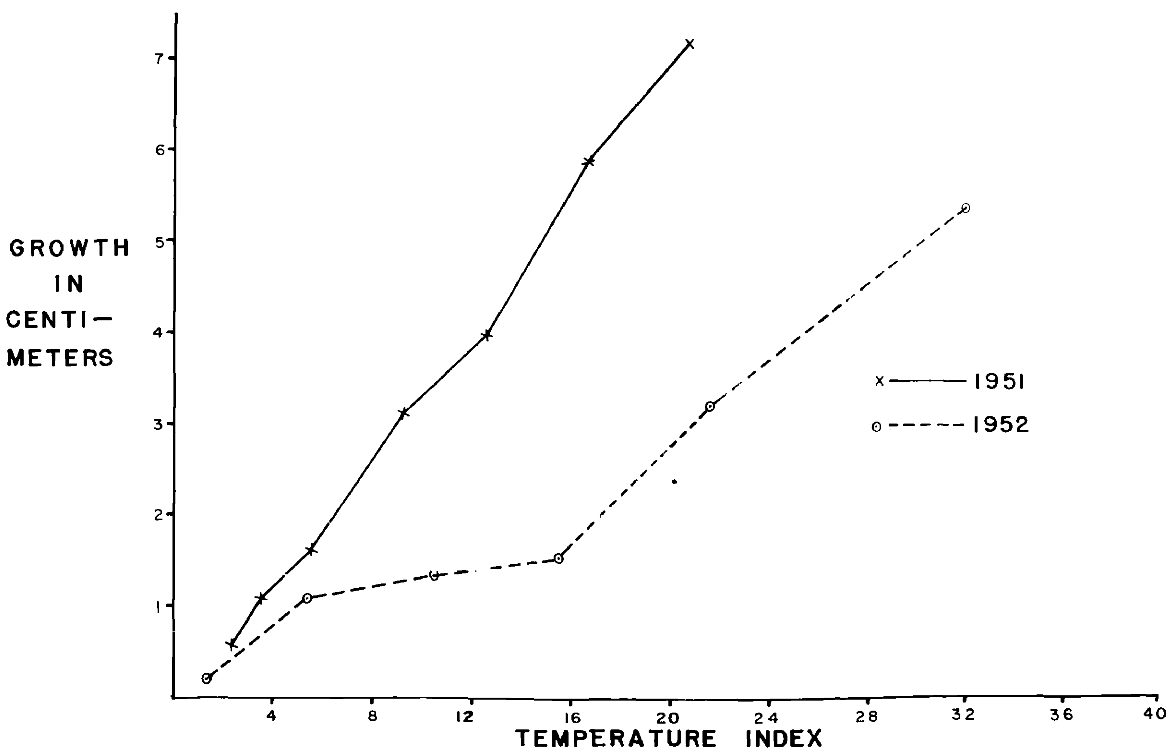


Figure 39. WEEKLY GROWTH AND TEMPERATURE INDEX FOR LADINO WITH ORCHARDGRASS

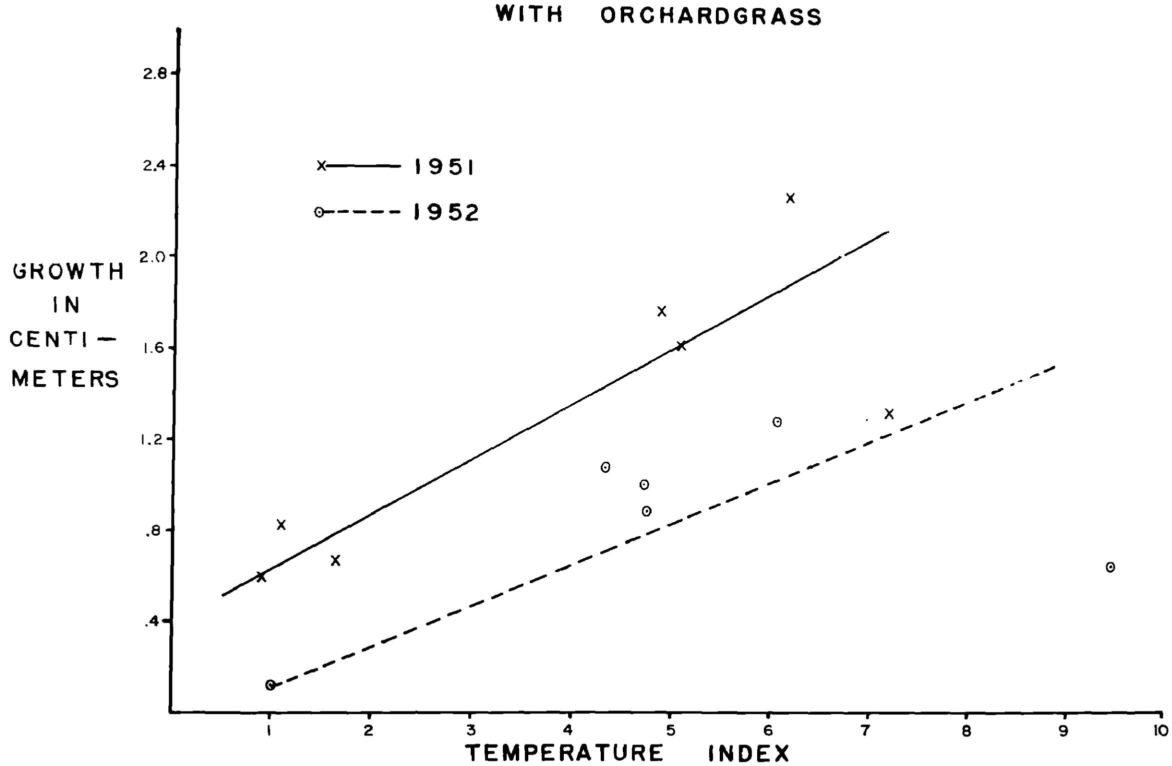
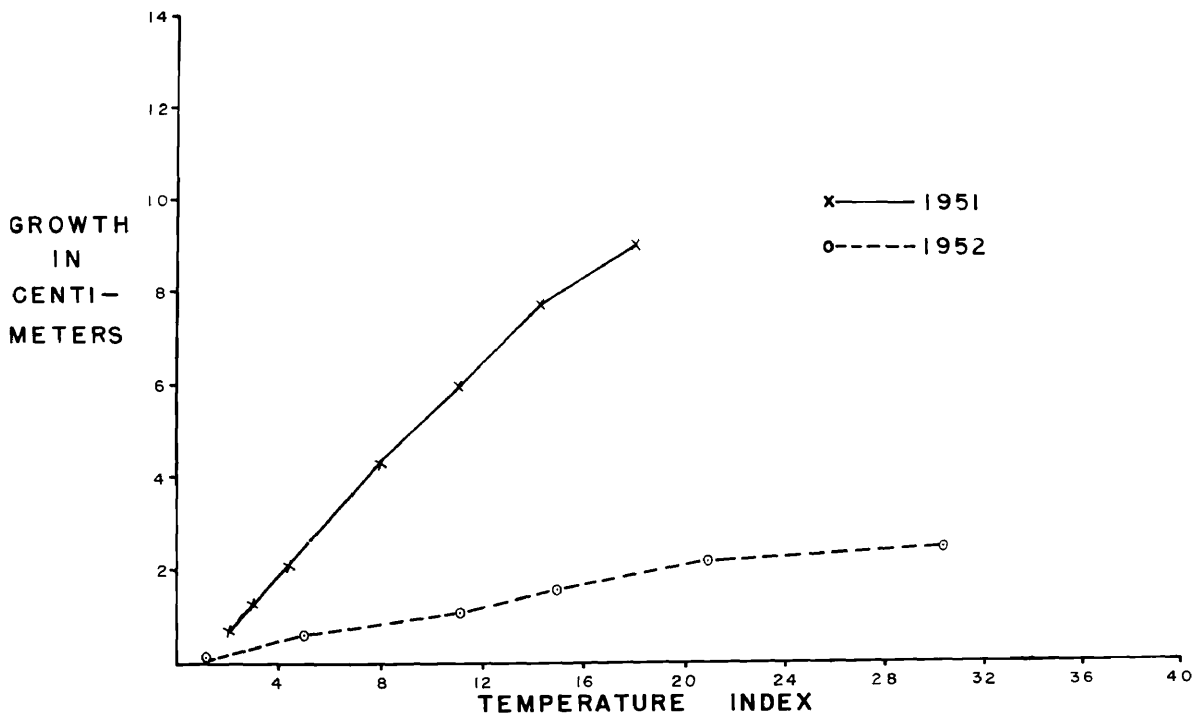


Figure 40. DEGREE DAY ACCUMULATION FOR LADINO CLOVER WITH ORCHARDGRASS



when in reality a very poor relationship existed. In studying these data further it was found that good agreement could even be obtained between two sets of randomly distributed numbers provided they were accumulated in this manner. To demonstrate this, a set of values was chosen from a table of normal random numbers and designated as growth rates. Another set of unrelated numbers was chosen and these were designated as temperature indices. When these data were plotted a typical scatter diagram was obtained, as shown in Figure 41. Since these two sets of figures were unrelated this is what would be expected. However, when these same data were accumulated a straight-line relationship between these two unrelated groups of values was found, as shown in Figure 42.

In view of these facts it seems rather important that anyone using this type of data presentation should be well acquainted with its limitations. It is also extremely important to those searching the literature since a rather large amount of temperature-growth data has been and still is being presented in this manner.

Winter Heaving

Winter heaving damage to forage crops and small grains in Maryland and other Northeastern states is often rather severe. A study of winter heaving in relation to temperature fluctuations and other climatic factors was begun during the winter of 1951-52. Most of the discussion will

Figure 41.

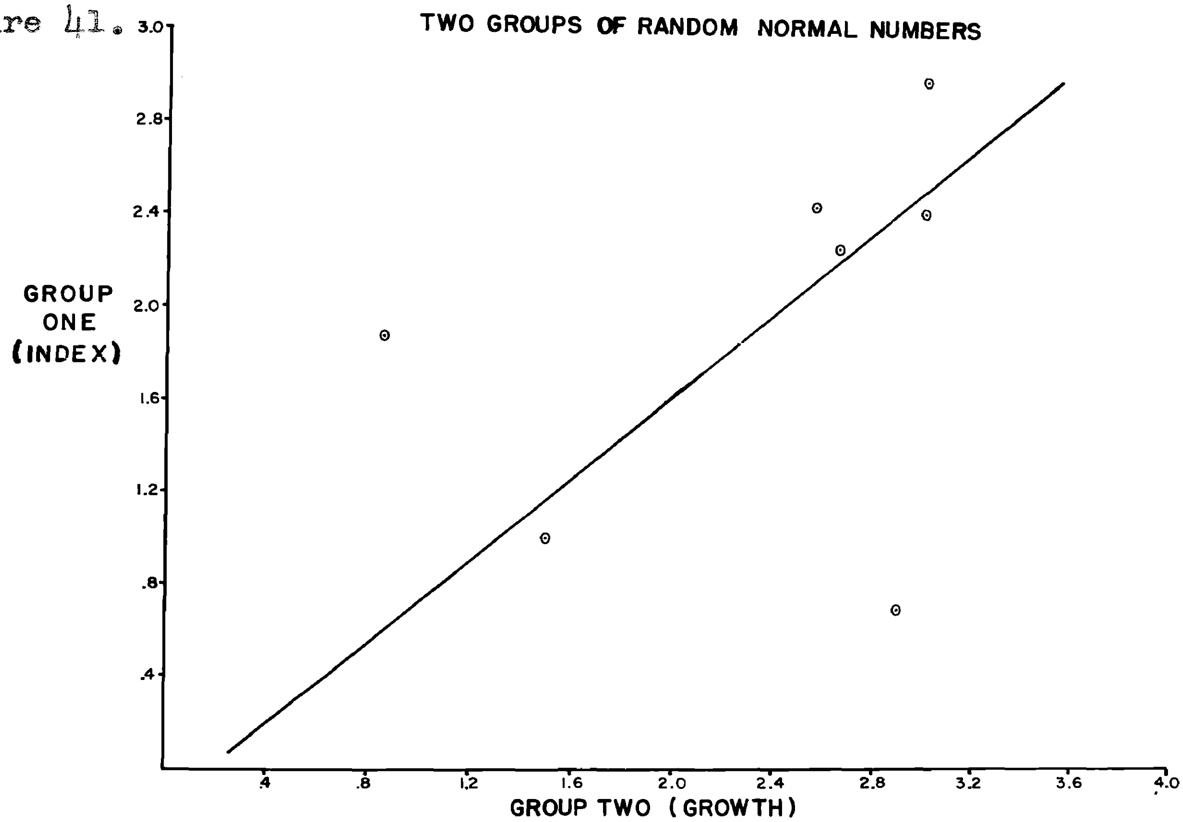
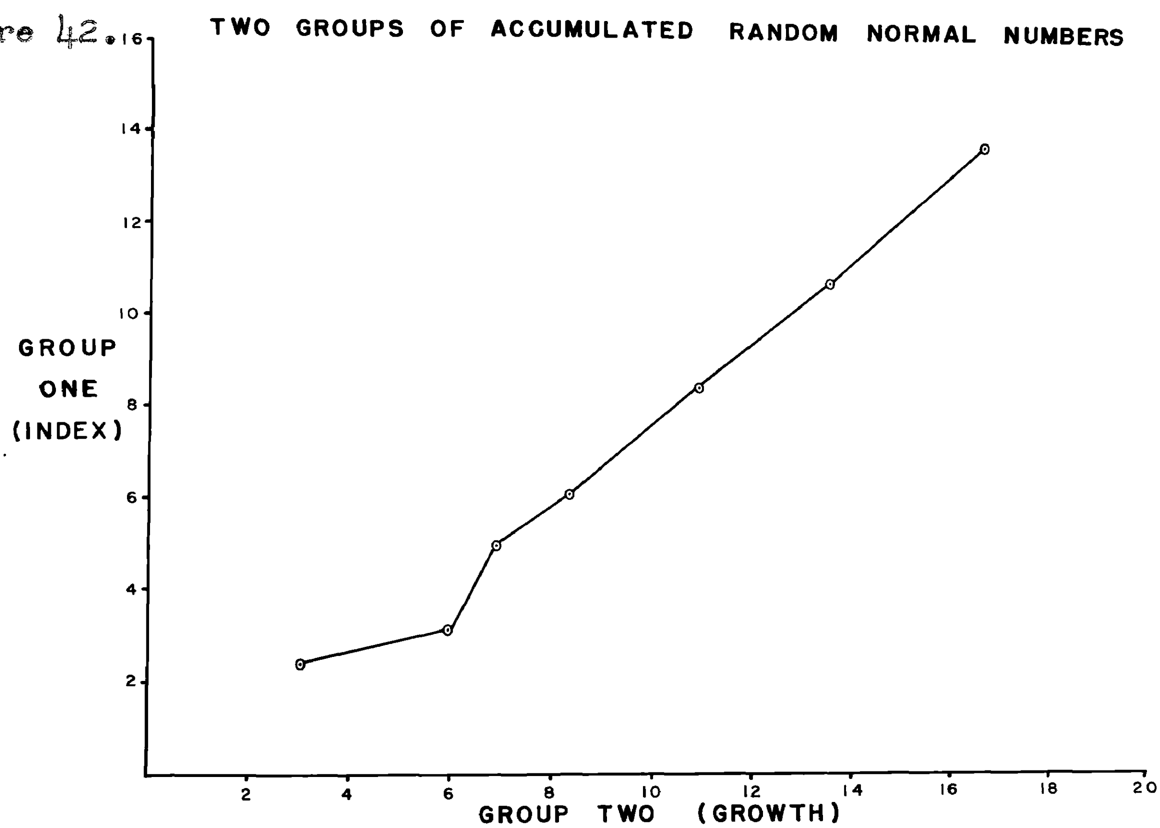


Figure 42.



deal with methodology and techniques in heaving measurements taken in the winter and spring of 1951-52, along with a measure of the sampling error found in such measurements.

The amounts of heaving in the various plots from the middle of December 1951 to the last of January 1952 are tabulated in Table 9. These values were obtained by measuring the upward movement of pointed wooden dowelings which were driven into the soil, as shown in Figure 9. There was considerable variation in the degree of heaving between measurement dates, the variation being more pronounced on those plots exhibiting the most heaving. The amount and uniformity of plant cover, or lack of such cover, had a marked effect on the amount of frost action. However, it was observed that a considerable quantity of crop residue was not necessarily essential providing the material was uniformly distributed. Very little difference was noted among the four peg diameters used. However, the depths at which these pegs were placed in the soil were important. A strong, positive relationship existed between depth of placement and the amount of heaving. An analysis of variance of these data is presented in Table 10. A significant difference was obtained for type of cover and for the cover by depth of placement interaction, while a highly significant difference was obtained for depths and for the depths by diameter interaction. In other words, one depth proved to be critical under one cover while a different level was critical under another cover. The larger pegs heaved less than the smaller ones when placed

Table 9. Amounts of winter heaving of wooden dowelings for two-month period from December 1951 through January 1952.

Depth of doweling in soil (inches)	Diameter of doweling (inches)	Heaving (centimeters) Bare ground	Ky. bluegrass	Other Species
4	1	7.00	.47	
	1/2	7.71	.62	
	3/8	8.73	.44	
	1/4	8.07	.51	
8	1	4.08	.24	
	1/2	6.61	.30	.98 1/
				.95 2/
				1.03 3/
				.63 4/
				.52 5/
	3/8	6.26	.21	
	1/4	6.05	.05	
12	1	4.57	.44	
	1/2	3.96	.34	
	3/8	4.21	.19	
	1/4	3.94	.34	
16	1	3.55	.17	
	1/2	1.29	.17	
	3/8	.89	.15	
	1/4	1.11	.10	

1/ Orchard grass
2/ Ladino clover
3/ Orchard grass-ladino clover
4/ Bromegrass
5/ Alfalfa

Table 10. Analysis of variance of winter heaving measurements on Kentucky bluegrass and bare ground plots 1951-52.

Source	degrees of freedom	mean square	F
Cover	1	33.425	8.736*
Dates	4	4.388	1.147
Dates X Cover (error a)	4	3.826	
Depth	3	3.135	6.258*
Depth X Dates	12	.549	1.096
Depth X Cover	3	2.324	4.639*
Depth X Dates X Cover (error b)	12	.501	
Diameter	3	.0003	<1.00
Diameter X Cover	3	.009	<1.00
Diameter X Dates	12	.068	1.838
Diameter X Depths	9	.146	3.946*
Error c	93	.037	
Total	159		

* significant at .05 level

at the shallow depths, while the reverse was true when placed at greater depths.

A separate analysis was made of the data from the peg movements in the orchard grass, orchard grass-ladino clover, bromegrass-ladino clover, ladino clover, and alfalfa plots and is presented in Table 11. Just as before there was a variation between dates, and the dates by association interaction was also significant. With respect to the other plots, the extent of heaving on the alfalfa and orchard grass plots did not increase as the winter season progressed. Heaving on those plots with ladino clover alone or with a grass tended to increase during the winter. There was also a slight tendency for more heaving in the orchard grass plot than in the bromegrass plots where the growth and consequently crop residue was more evenly distributed over the area. This was true even though bromegrass was somewhat less vigorous in its growth habits.

The pegs were arranged systematically in each plot and for this reason the variation between pegs within each plot could not be measured with the conventional analysis of variance. An analysis of the experimental error was made by removing autocorrelations as described by formula (J), page 45. A summary of the variation found under the various types of cover is presented in Table 12. Relatively low standard errors were obtained in all instances except with one plot of orchard grass and one of orchard grass-ladino clover. The relative standard error was well within the range tolerated

Table 11. Analysis of variance of winter heaving measurements on bromegrass-ladino, orchard grass-ladino, orchard grass, ladino, and alfalfa plots, 1951-52.

Source of variation	degrees of freedom	mean square	F
Dates	4	.35900	65.992*
Associations	4	.01450	2.665
Dates X Associations	16	.02075	3.814*
Between duplicate plots (error)	25	.00544	
Total	49		

* significant at .05 level

Table 12. Effect of plant cover on the variation of heaving measurements within individual plots.

Average heaving rates for each peg used for these determinations

Type of Cover	Plot I: Mean (95% Confidence)	Plot I: Standard Error of Means	Plot I: Twice Relative Standard Error (95% Confidence)	Plot II: Mean (95% Confidence)	Plot II: Standard Error of Means	Plot II: Twice Relative Standard Error (95% Confidence)
Alfalfa	.607 ±.0209	.0101	3.51	.599 ±.0139	.0066	2.32
Orchard Grass	.705 ±.2404	.1134	34.09	.581 ±.0227	.0107	3.91
Orchard Grass-Ladino Clover	.743 ±.2618	.1235	35.26	.642 ±.0556	.0262	8.66
Bromegrass-Ladino Clover	.642 ±.0436	.0206	6.79	.612 ±.0277	.0131	4.53
Ladino Clover	.708 ±.0443	.0208	6.25	.659 ±.0155	.0073	2.35
Ky. Bluegrass	.560 ±.0114	.0054	2.03			
Bare Ground	1.692 ±.0971	.0458	5.74			

by field experiments of this type except with the orchard grass plots. This variation was caused in each case by one or two of the pegs which happened to be located in an area essentially free of crop residue. In future experiments this could be stratified out.

Temperature Sampling

The temperatures used in all of these studies were taken from a single point within each plot, i.e. one point for each level within the plot. Since a single thermocouple sampled only one point of the area it seemed desirable to determine how accurately this one point described the temperature for that stratum above or within the plot. To obtain a measure of the variability the plot area was divided into six equal blocks. Two points were located at random within each block and the temperature recorded for each of these locations. Sampling data obtained in this manner for temperatures one-half inch below the soil surface in bare ground, bluegrass, orchard grass, orchard grass-ladino clover, and ladino clover plots are presented in Table 13. It can be seen that the uniformity of plant cover greatly reduced the sampling error. The largest sampling error was obtained for the orchard grass-ladino clover plots, with the next largest value for the orchard grass plots. The lowest values were obtained from the bluegrass plot which had a uniform turf. It should be noted that the standard error was less than one in all cases, and only in the case of the orchard grass-ladino clover plot

Table 13. Sampling of one-half-inch soil temperatures within bare ground, Kentucky bluegrass, orchard grass, ladino clover, and orchard grass-ladino clover plots. Weather was slightly cloudy with a medium wind. Samples taken 11 April 1952.

Type of Cover	Random sample within blocks	Blocks 1	2	3	4	5	6	Standard error of mean	Twice relative standard error (95%) (confidence) %	Mean temperature (95%) (confidence)
Bare ground	X_1	68.2	68.6	68.2	68.1	68.0	68.4			
	X_2	68.7	68.0	68.2	68.1	68.0	68.5	.066	.21	68.2 ± .144
Kentucky bluegrass	X_1	68.3	62.5	63.6	62.8	61.9	61.8			
	X_2	63.7	62.5	63.6	63.1	62.3	61.8	.042	.15	62.8 ± .093
Orchard grass	X_1	65.7	65.5	62.6	62.1	60.6	61.5			
	X_2	64.6	65.1	64.6	60.3	60.6	64.0	.320	1.01	63.1 ± .704
Ladino clover	X_1	72.5	67.7	68.6	65.8	65.8	67.0			
	X_2	71.9	69.6	67.4	68.0	67.0	67.0	.285	.92	68.2 ± .627
Orchard-Ladino	X_1	60.9	64.1	65.7	64.8	61.6	58.7			
	X_2	65.8	62.8	62.6	64.0	59.5	58.4	.530	1.87	62.4 ± 1.167

did the 95 per cent confidence interval exceed one. The temperature recorder used in this study was accurate to within one degree; consequently the accuracy of the measurements would not have been substantially increased by sampling more than one point within each plot.

Although the error involved in sampling air temperatures was slightly larger than those involved in sampling soil temperatures, they were still small, as is shown in Table 14. After the orchard grass and ladino clover had made some spring growth, another set of soil temperatures were collected along with air temperatures at three and twelve inches above the soil surface. The three-inch air level was beneath the foliage canopy in both cases. The twelve-inch level was well covered in the orchard grass plots. Whether the thermocouple was inside the herbage or above it, the experimental error was small. When the orchard grass was two to three inches high, the relative standard error for soil surface temperature measurements was 1.01 per cent, but after the foliage reached a height of two feet, the value was reduced to 0.42 per cent. This buffering action increased as the height and density of growth increased. Ladino clover plots had not made sufficient growth to uniformly cover the area. This resulted in increased sampling errors for those plots. However, in most cases the sampling error was within the accuracy of the recorder.

Air temperatures were also accurately measured by only one point within the plot. This was true whether the

Table 14. Sampling of air and soil surface temperatures on orchard grass and ladino clover plots. Weather was clear and calm. Average height of orchard grass was 18 to 24 inches, while ladino clover was from four to six inches high with very sparse coverage on parts of the plot. Samples were taken 9 May 1952.

Type of cover	Level	Random sample within blocks	Blocks 1	2	3	4	5	6	Standard error of mean	Twice relative standard error (95%) (confidence) %	Mean temperature (95%) (confidence)
Orchard grass	Soil surface	X_1	64.3	61.9	62.8	62.8	62.1	62.0			
		X_2	63.2	61.9	62.8	61.7	62.1	62.2	.130	.46	62.5 $\pm$ .287
	3" air	X_1	73.8	74.6	71.7	76.4	73.0	73.3			
		X_2	77.3	74.7	73.4	73.5	73.0	73.9	.408	1.21	74.0 $\pm$ .897
	12" air	X_1	78.3	81.3	79.9	79.2	78.4	80.4			
		X_2	80.8	79.6	82.0	78.7	79.0	80.8	.315	.87	79.9 $\pm$ .694
Ladino clover	Soil surface	X_1	76.8	75.1	78.3	74.4	79.7	84.5			
		X_2	78.6	84.6	78.7	74.4	76.8	85.6	.847	2.33	80.0 $\pm$1.864
	3" air	X_1	80.4	82.2	86.7	88.5	86.1	87.6			
		X_2	82.0	82.9	87.5	86.0	84.8	87.4	.285	.74	85.2 $\pm$ .626
	12" air	X_1	78.7	80.0	83.8	88.6	84.2	84.2			
		X_2	81.9	83.7	87.9	84.2	84.2	85.9	.661	1.73	83.9 $\pm$1.455

temperatures were taken within the herbage or above the foliage canopy. It can be seen in Table 14 that an average difference of nearly six degrees was obtained between the 3- and 12-inch air levels within the orchard grass plots yet the standard error did not change appreciably. After the orchard grass had grown about 18 inches the sampling error for the soil surface became very small. It was also small at the 12-inch height where the foliage was less dense. The sampling error was somewhat higher at the 3-inch level where the herbage was less uniform, being very dense in spots and relatively sparse at other locations. However, in all cases the experimental error was very small.

Since it is often necessary to use temperature values obtained from instruments in a weather shelter, it seemed desirable to find out how closely the temperatures obtained inside and outside a standard Weather Bureau shelter compared. Wide differences in temperature readings were observed on very calm days, but differences were small when the average wind speeds were three miles per hour or above. A few examples of the variations found can be seen in Table 15. When wind speeds were less than one mile per hour, the daily average temperatures for the two locations often differed by as much as ten degrees, while a difference of 4.7° F. was the largest observed when the wind speeds were between three and four miles per hour, since at these speeds the air was well mixed. This lag in temperature change may not be important under most conditions. However, when detailed

Table 15. Effect of wind speeds on temperatures recorded inside and outside of a standard Weather Bureau shelter. Days were grouped according to wind speed; then days within these groups were chosen at random.

Average wind speed (miles/hour)	Inside weather shelter temperature (degrees Fahrenheit)			Outside weather shelter temperature (degrees Fahrenheit)		
	Maximum	Minimum	Average	Maximum	Minimum	Average
less than one	78.0	55.8	66.9	90.2	57.4	73.8
	71.4	52.0	61.7	77.0	53.0	65.0
	70.0	47.0	58.5	78.3	47.0	62.7
	57.8	40.0	48.9	59.6	45.1	52.4
	66.0	32.5	49.2	45.0	33.0	39.0
3-4	80.0	50.2	65.1	80.0	52.1	66.0
	86.7	65.8	76.2	87.5	66.4	77.0
	82.3	60.0	71.2	83.0	50.0	66.5
	86.7	65.8	76.2	87.1	66.2	76.7
	49.0	25.0	37.0	49.0	25.0	37.0

analyses are being made it may very well be serious. This would be true if one were relating temperature to plant response, or in any study where it is desirable to measure local variations.

Light Sampling

Light readings were made within several types of plant cover at different heights. A few examples of the proportion of light reaching the various levels within orchard grass, orchard grass-ladino clover, and alfalfa plots can be seen in Table 16. The plots were divided into six blocks with two points being located at random within each block. As far as possible the light readings were made on calm days to eliminate the variability caused by wind movement. The orchard grass plants averaged between 18 and 24 inches in height with the largest portion of leaves in the lower one foot. On days when the outside reading was 10,000 foot-candles an average of only 2,792 foot-candles reached the 12-inch height. This value was reduced to 104 foot-candles one inch above the soil surface. Readings as low as 22 foot-candles were measured at some points. A slightly greater amount of light reached the same level in the orchard grass-ladino clover plots with an average of 369 foot-candles reaching the one-inch level. With an average outside reading of 2,492 foot-candles the alfalfa planting reduced the average light at the one-inch level to 106 foot-candles. The average height of the alfalfa was approximately eight inches

Table 16. Light readings in mature stands of orchard grass, orchard grass-ladino clover, and alfalfa. The readings above the herbage were taken immediately following those inside. All measurements expressed in foot-candles.

	Orchard Grass			Orchard Grass-Ladino Clover		Alfalfa	
	height of reading			height of reading		height of reading	
	three feet	twelve inches	one inch	three feet	one inch	three feet	one inch
	10,000	3,500	90	9,900	580	2,600	85
	10,000	4,700	22	10,000	460	2,500	300
	10,000	2,300	190	10,000	600	2,500	84
	10,000	2,700	59	9,800	300	2,400	70
	10,000	4,300	190	9,800	150	2,400	140
	10,000	3,200	250	9,800	1,000	2,500	130
	10,000	1,900	33	9,800	73	2,500	130
	10,000	1,600	40	9,800	120	2,500	38
	10,000	2,200	180	9,500	180	2,500	47
	10,000	3,400	100	10,000	600	2,500	110
	10,000	1,200	60	10,000	160	2,500	70
	10,000	2,500	40	10,000	200	2,500	53
AVE.	10,000	2,792	104	9,867	369	2,492	105

less than the orchard grass. Other measurements were made, but these serve to illustrate the extent to which foliage intercepts and prevents light from reaching the soil surface. The field crop's ability to compete with summer weeds and grasses is closely associated with its ability to prevent light from reaching young weed seedlings in the early summer, thus preventing their growth.

It seemed desirable to find a method of sampling light intensities which would give maximum results with a minimum number of observations. The first and most logical step, then, appeared to be a study of the sampling error involved in making light measurements in a crop of this type. A summary of some of the data collected during the study is included in Table 17. The standard errors were much larger than those found for temperature sampling as was to be expected. The relative standard error was less than the desired 10 per cent only once of the nine examples used. These values ranged from 6.4 to 24.3 in the orchard grass plots. The error was consistently lower for the 12-inch height than for the one-inch height where the bunch type growth of orchard grass caused a greater variation in light penetration. If the most variable plot is considered, it would be necessary to take three times as many observations to reduce the sampling error to an acceptable value. It is clear that smaller strata and a larger number of sampling

Table 17. Summary of experimental errors involved in light measurements made within the herbage of several forage crops.

Type of vegetation	Height of observation (inches)	Average plot ratio 1/ (95% confidence)	Standard error of mean	Twice Relative standard error (95% confidence)
Orchard grass	1	.001001 ± .000139	.000063	13.9
	12	.278085 ± .017848	.008109	6.4
Orchard grass	1	.011343 ± .001944	.000883	17.1
	12	.332418 ± .051867	.023565	15.6
Orchard grass	1	.006644 ± .001316	.000598	19.8
	12	.241042 ± .044491	.020214	18.5
Orchard grass	1	.018570 ± .004516	.002052	24.3
Orchard grass-Ladino clover	1	.037294 ± .008012	.003640	21.5
Alfalfa	1	.041602 ± .006790	.003085	16.3

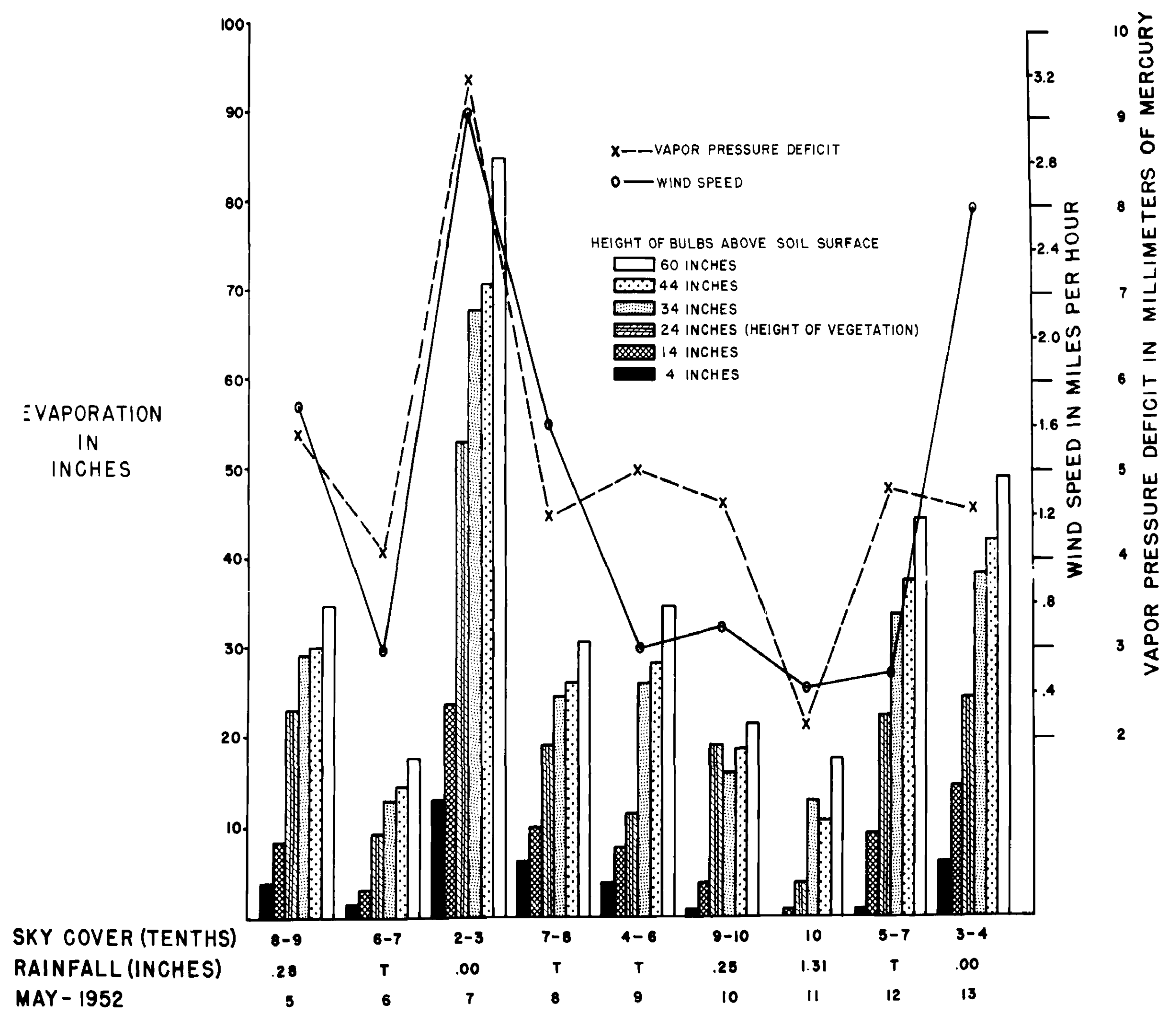
1/ Ratio obtained by taking a reading inside the herbage and then immediately taking a full sunlight reading. The ratios thus obtained were used in all calculations.

points are needed. From the data given here, adequate sampling schemes could be devised.

Evaporation Rates

Evaporation data were collected only during the normal growing season. In order to learn more about the effects of various environmental factors on the rate of evaporation, a limited but rather detailed study was made for a period of nine consecutive days. Plant cover, wind speed, relative humidity, temperature, sky cover, and rainfall were some of the factors studied. The orchard grass sward was approximately 24 inches tall at the time of this study. These data are presented in Figure 43. The most striking observation that can be made is that evaporation rates were closely correlated with wind speed and vapor pressure deficits. This was especially true at the levels above the vegetation. These relationships are as expected, but the magnitude of the daily changes with fluctuations in weather conditions were most striking. Even though high wind speeds were always associated with high evaporation rates and low wind speeds with low evaporation rates, vapor pressure deficits appeared to play an even greater role. The average wind speed increased from around 0.5 miles per hour on the 12th of May to 2.6 miles per hour the following day. During the same time the evaporation rate increased very little, the vapor pressure deficit decreased slightly, and the sky cover was reduced. The increased wind speed

Figure 43. EFFECT OF SEVERAL FACTORS ON EVAPORATION RATES FROM SPHERICAL ATMOMETER BULBS IN ORCHARD GRASS PLOTS



appeared to have had little effect in this case. The height and density of plant growth had a significant influence on the rate of water loss. On May 7, 85 inches of water were lost by evaporation at the 60-inch height, while at the 4-inch height, approximately 20 inches below the top of the grass canopy, only 13 inches of water were lost. The evaporation gradient from the 4-inch to the 60-inch level formed a general pattern for each day with the greatest increase in evaporation occurring at the top of the grass canopy. This was less pronounced on rainy days. The extremely high evaporation rates at the 24-inch level with respect to the other levels on May 10 can be explained in part since it was at this level that the highest temperatures were recorded. These data emphasize the importance of considering all environmental variations when studying evaporation rates.

The amount of water lost from the white atmometer bulbs was consistently less than the amount lost from the black bulbs. This was true whether the bulbs were placed at 3 or 60 inches above a Kentucky bluegrass sod. Evaporation rates were also measured in orchard grass, orchard grass-ladino, and ladino clover plots. A summary of these data from June 7 to September 27, 1951 is presented in Table 18.

The evaporation rates in the taller growing species were consistently lower than for the same level over the Kentucky bluegrass plot. However, the differences between the taller growing species were small. It was even

Table 18. Weekly average evaporation rates from spherical atmometer bulbs placed in bluegrass, orchard grass, orchard grass-ladino clover, and ladino clover plots from June 7 to September 27, 1951.

Inches of Water Lost

	Black Bulbs		White Bulbs				
	Blue-grass		Blue-grass		Orchard grass	Ladino clover	Orchard grass-Ladino clover
	Height above soil surface (inches)						
Week ending	3	60	3	60	3	3	3
6-7	27.9	47.6	15.4	22.7	18.8	16.0	19.0
14	16.0	18.6	8.7	12.2	8.3	7.0	8.4
21	35.8	44.7	18.1	27.2	15.1	11.7	15.4
28	34.2	43.3	17.5	25.7	9.2	6.3	8.9
7-5	32.0	40.9	16.5	25.0	6.3	6.1	5.7
12	46.0	58.9	27.9	40.7	9.0	16.7	11.3
19	24.8	31.0	13.3	20.2	16.3	14.6	16.0
26	31.8	37.7	17.3	27.0	16.5	13.8	15.5
8-2	37.5	49.9	20.3	32.4	14.8	15.9	17.3
9	27.8	41.9	16.7	23.5	19.3	13.1	14.7
16	33.1	39.8	19.1	27.7	11.2	15.2	17.4
23	44.8	54.0	31.1	38.9	22.3	26.7	30.8
30	49.7	58.0	28.7	33.9	28.2	30.1	33.6
9-6	26.4	28.5	17.8	22.1	18.6	19.5	20.0
13	35.0	36.0	19.5	30.0	20.0	24.0	23.2
20	25.9	34.8	13.8	22.1	12.4	16.6	15.1
27	30.0	34.9	18.9	29.5	14.9	18.0	18.5

difficult to pick out any significant trend among any of the taller species.

Evaporation data were collected for only the bluegrass and orchard grass plots in 1952. However, the water loss was measured for three levels in the orchard grass and four in the Kentucky bluegrass plot. Only the white atmometer bulbs were used in 1952. These data from June 23 to August 4 are summarized on a weekly basis in Table 19.

The amount of water loss was almost directly proportional to the height of the bulb and density of the vegetation. When the orchard grass was cut to approximately the same height as the bluegrass there was little difference in evaporation rates. However, as the orchard grass increased in height the water loss from a given height tended to decrease. This was especially true as the vegetation covered the atmometer bulbs. However, even at the 24-inch height, which was well above the canopy of growth of both species, evaporation rates were consistently higher over the bluegrass plot. When the orchard grass was 10 to 12 inches high it was observed that water losses from the 12-inch height over the bluegrass and the 24-inch height over the orchard grass were about the same. This seems logical since in each case the bulbs were approximately the same distance above the vegetation. The differences that did occur appeared to be due more to the height of the bulbs relative to the height of the herbage and density of plant growth than to any differences among the species being grown. However, the gradients obtained on the bluegrass plot tended

Table 19. Weekly evaporation rates from white spherical atmometer bulbs placed at various heights over bluegrass and orchard grass swards. Data from June 23 to August 4, 1952

Inches of water lost

Week ending	Bluegrass				Orchard Grass		
	Inches above soil surface				Inches above soil surface		
	3	12	24	60	3	12	24
6-30	17.4	22.7	26.6	30.9	2.9	11.8	22.2
7-7	20.0	25.3	29.8	34.4	14.6	21.2	26.1
7-14	14.6	20.5	24.5	29.4	16.3	22.2	24.4
7-21	16.9	22.3	27.4	32.6	16.3	22.0	26.8
7-28	23.2	28.4	35.1	41.3	16.9	30.4	34.4
8-4	21.0	24.1	28.6	33.1	15.2	25.5	27.6

to be somewhat less than those for the orchard grass even for the few days following harvests when the height of herbage was essentially the same for both species.

DISCUSSION

The plant microclimate has been variously referred to as the climate of the area below a height of five feet, that within the plant layer, or even merely as the area near the soil without definite limits of height. It may be differentiated from macroclimate in its attempt to measure local effects. In this study the main emphasis was placed on the environment of this local variation which is superimposed on the macroclimate. The effect of macroclimate would exhibit itself as differences between the response of plants at the various locations of the NE-10 Regional Variety and Strain Test. The differences between response of plants at any one of these locations, or the differences in plant response between years at each location are due to the local variation, the microclimate. Examples of this are numerous in Maryland. Red clover stands, in some areas, are almost entirely eliminated during some years, while the same varieties planted on the same land may perform relatively well the following year. Heaving injury to ladino clover may be more pronounced in one year than another.

The data collected during this study seemed to have their greatest value in re-emphasizing the importance of various climatic factors in forage crop production. Stand survival and maintenance of the desired grass-legume mixture are often affected as much by weather conditions as by any other factor. Problems of soil fertility, seedling establishment, defoliation practices and general management problems are all paramount in determining the production, quality, and persistence of forages. However, these management practices would be enhanced by constantly bearing in mind the many climatic factors involved. This becomes more important when both grasses and legumes are grown together in a single sward. If pastures contain the taller growing species, rotational grazing is the practice generally recommended. Such a practice increases the carrying capacity and prolongs the life of the stand. The usual recommendations are that after each grazing ladino clover should be allowed to reach a height of 8 to 15 inches before it is grazed again. It should not be pastured closer than 3 to 5 inches since close, continuous grazing delays recovery growth, weakens the plants and encourages the encroachment of weedy species.

Perennial weeds such as wild morning-glory (<u>Cirsium arvense</u> Scop.) have been controlled by proper timing of cultivations. After reviewing much of these data, Robbins, Crafts, and Raynor (68) state that best results were obtained when wild morning-glory was allowed to grow for several days after new shoots emerged before the next cultivation was made. During this period the plant tends to exhaust its reserves instead of adding to them, and if this practice is continued, the carbohydrate reserves become so low the plant can no longer survive. Improper timing of clipping or grazing may have a similar effect, especially if drought prevents plants from making sufficient recovery growth. This not only reduces yields but also causes a reduction in plant vigor. Lovvorn (51) found that with Dallis grass (Paspalum dilatatum), carpet grass (Axonopus affinis), Bermuda grass (Cynodon dactylon), and Kentucky bluegrass fertility levels and cutting treatments were more important than light and temperature on top growth yields. However, the lowest temperature used was 60° F. Yields decreased more by frequent cuttings at high temperatures and higher fertility levels than at the lower levels for these two factors. It appears, therefore, that more careful management is required at the higher fertility levels and in regions where high temperatures occur. The interaction of local climate and management was forcefully demonstrated during the summer of 1951 when rainfall was well below the long-time average for this area during the latter part of the growing season. Because of its rather shallow root system, ladino clover is rather sensitive to relatively short droughts. This is especially true when it is grown with a relatively vigorous grass such as orchard grass. Droughty conditions appear to be more hazardous following clipping or grazing when the root reserves have been lowered by the early recovery growth. These were the conditions which existed in midsummer of 1951 when recovery growth following the second harvest was essentially stopped approximately ten days after harvest. There was inadequate moisture during the remaining summer months for any appreciable growth to take place. A third harvest was removed from the area in late August. This tended to further reduce the carbohydrate reserve. The few plants that did survive this summer drought were unable to make any appreciable fall growth with the result that most of the clover went into the winter in extremely poor condition. It was unusually vulnerable to heaving and other types of winter injury because of the low carbohydrate reserve in roots and stolons and because of the high percentage of older tissue remaining.

Toward the end of the summer when the drought conditions became most severe a difference was noted in the amount of growth made on certain plots. Later on, in looking over the soil moisture percentages from the various plots, it was observed that in those plots where a larger amount of growth had taken place there had also been a more favorable moisture supply. This was true for the 3-, 10-, and 18-inch soil levels. As a result of these more favorable growing conditions a larger percentage of plants in these plots were able to survive the dry period. The surviving plants in these plots also made more fall growth and were able to replenish in part their depleted carbohydrate reserves. The increased growth also tended to minimize the effects of winter freezing and thawing by producing a more uniform covering over the soil surface. Less heaving occurred under these conditions, and the heaving that did take place was more uniform, which tended to reduce further plant damage.

The complete answer for loss of clover stands undoubtedly does not lie in these factors alone, but from the data collected and from daily observations made throughout the year they appear to be extremely important. Although detailed heaving measurements were not made during the winter of 1950-51 there appeared to be as much, if not more, winter heaving than occurred the following year when detailed measurements were made. This was based on a comparison of the degree to which permanent plot stakes were heaved during the two years. It was also based on the temperature records for the two years. One needs only to refer to Figure 10 to see that temperatures during January and February of 1951 were lower than for the following year. It should also be mentioned that temperatures for December of 1950 were also below those for the following December. However, monthly average temperatures do not furnish the complete story. Although long cold periods result in greater frost penetration, frequent freezing and thawing with relatively shallow frost penetration appear to be more hazardous as far as Ladino clover is concerned. This is true because of its relatively shallow root system and because any heaving of the soil results in heaving of the plant since the stolons lie directly on the soil surface. Even though heaving conditions were severe during the 1950-51 winter period the added cover provided by adequate fall growth prevented any appreciable plant damage. This can be best seen by comparing Figures 17, 18, and 20 which show essentially three degrees of plant cover and likewise three degrees of stand survival. There was essentially no loss of stand during the 1950-51 season while two degrees of injury are shown for the following year.

When periods of rather severe heaving are followed by only a few days of temperatures around 50° F. organisms such as Sclerotinia spp. grow rapidly and obtain easy access to the injured roots and stolons. If the period of severe winter heaving is followed by a few days or weeks of cold, dry winds the exposed parts may be badly desiccated. It is difficult indeed to separate the effects of these two factors since their injurious effects are compounded under most conditions. Situations such as these cannot always be corrected, but management practices can be modified to give the greatest advantage possible to the crop plant. In instances where supplemental irrigation can be supplied many of these problems may be largely corrected provided proper fertility and management practices are also followed.

Temperature in relation to plant growth and development has been the object of many investigations. Growth is a very complex phenomenon, yet a commonplace process and one of the outstanding characteristics of living matter. It is a process which is difficult to define. It may be considered in terms of whole organisms or in terms of individual plant parts. In general, growth involves the production of new protoplasm, the formation of new cells, and cellular enlargement and specialization. The formation of new living matter is always accompanied by an increase in total weight and usually by an increase in total volume of the system. There seems to be no one definition of plant growth which is applicable under all conditions, nor does there seem to be a single criterion to use in measuring growth.

The difficulties in relating growth to temperature become apparent when it is realized that growth is in reality a complicated summation of a number of individual processes, each of which is also influenced by temperature. The kinetic energy of molecular systems, viscosity, solubility, diffusion, reaction velocities and an array of biochemical reactions in plants are a few examples of the many processes involved in growth that are in turn influenced in some way by temperatures.

Lundegardh (52) writes, "Summer growth, the development of storage organs, fruits and bulbs is naturally very closely bound up with carbohydrate assimilation. Growth in the spring depends upon assimilation less closely, for the young shoots are scarcely able to assimilate for themselves, and they draw their nourishment from stored materials in rhizomes, roots and bulbs. In the spring, therefore, the direct action of the temperature upon growth controls development, while in the summer, growth is dependent upon assimilation, which, in its turn is controlled by temperatures."

The minimum temperatures for growth have been defined as the lowest temperature at which plants will continue to grow without injury after a specified period of exposure. The exact minimum temperatures are difficult to determine precisely since growth rates are so slow at low temperatures.

Although the theory of an optimum temperature is a rather simple concept, its precise definition is difficult. In general, it may be stated that growth rates tend to increase with temperature until a condition is reached where the accelerated activity cannot be maintained and growth is depressed.

It seems logical that with careful work it should be possible to determine a temperature point at which a maximum growth rate could be maintained independent of the time factor. Leitch (45) has defined this optimum temperature as the highest temperature at which there is no time factor operating and distinguished a maximum-rate temperature as the temperature at which the growth process attains its highest value. We do not have at the present time, for a single plant, the temperature-growth curve for the whole organisms at the various stages of its development along with changing external conditions such as light, water, nutrition, etc. If this information were available for even one of the higher plants it would be extremely helpful in future work of this type. Most workers agree that each developmental phase of a plant's growth is characterized by a different growth curve, but we know comparatively little about the shape of these curves.

In this study it was found possible to obtain a measure of the relative amount of heat which was accumulated by the soil before any appreciable spring growth was made. This was accomplished by choosing a base temperature and determining the number of hours throughout the day and night that temperatures were above this value. By weighting each increased temperature above this base value a measure of heat accumulation was obtained. It was reasoned that an increase of two degrees above the base temperature would have a greater effect on initiation and rate of growth than would an increase of only one degree, and that two hours of the increased temperature would be more effective than one hour. Formula (G) was used in an attempt to properly weight each increased temperature reading for the entire 24-hour period. When this procedure was followed, values were obtained which were essentially the same for a particular species during the two years of this study. Differences between species were also observed. For example, in 1951 660 units were accumulated in the orchard grass plots before growth started, while 1335 units were accumulated in the ladino clover plots the same year. Bluegrass also seemed to require higher temperatures for growth initiation, but this difference was not as pronounced. These data are by no means conclusive, but it is felt by the writer that, in time, rather accurate predictions could be made on the initiation of spring growth of such forage crops. In time it should be possible to devise probability tables and from these predict dates when grazing could begin in certain localities, provided previous grazing management and levels of fertility were considered, just as the percentage of soft corn has been predicted in Iowa by Shaw and Thom (74).

In this study correlations between growth rates and temperature from the last of February to the latter part of May were very high. This was true regardless of the manner in which temperature values were calculated. This merely means that temperatures were in all probability the one factor most limiting growth during this particular period of time.

Perhaps more information was obtained from these data when the growth rates and the temperature-growth indices were plotted as weekly and as seasonal accumulations. Very similar growth curves were obtained for all of the species during both years of the study. However, the shape of the curve was slightly different for each species. The most striking difference was, however, between years for the same species. The effect of years had a significant influence on the slope of the line. This was true in every case. The slope of the bluegrass growth curve was affected least by the difference in temperature for the two years. These differences seemed to be as closely associated with stability of temperature increase as with the actual increase itself. In the early stages of spring growth, and perhaps at any other time, plants seem to be quite sensitive to sudden changes in temperature. It is true that plants do not generally respond to small changes in temperature especially if they are of short duration. However, the effect of sudden temperature change cannot be entirely neglected. Lundegardh (52) writes that the "shock" effect of temperature, which is usually of short duration, may or may not have much ecological importance but is of importance when one is trying to relate results from experiments conducted under controlled conditions to those actually found in the field where conditions are constantly changing. In this study the shock caused by cool temperatures of relatively short duration appeared to have been one of the main causes for the difference in growth rates for the two years. This appeared to be logical since this was the only weather factor found to be substantially different for these two years except that rainfall was greater during the 1952 spring season. However, soil moisture was near field capacity during the period when growth measurements were being made for both years. The larger amount of rain for the second year may have tended to increase the soil temperature at the lower levels thus stimulating a larger amount of root growth at an earlier date which in reality tended to increase the effectiveness of increased temperature. Water has the ability to absorb large quantities of heat which can be released to the surrounding soil as it moves to the lower soil levels.

Another point that should be emphasized concerning these data is that accumulations of temperature-growth data can be hazardous if they are not used properly. In all of the growth rate studies better overall agreement was obtained when temperature and growth data were accumulated for the total spring season. This appeared on the surface to be an excellent way to study temperature-growth relationships since the accumulation of these data tended to smooth out the irregularities found in such growth rate curves. However, the results of this procedure became alarming when certain groups of growth data, which were for all practical purposes independent of temperature, were accumulated in this manner. In such cases excellent agreement was obtained between growth and temperature when in reality the two sets of data appeared to be independent.

It seemed obvious that the degree-day accumulation was a fallacious method to use in relating temperature and growth since good agreement was obtained when in reality no relationship existed. An attempt was made to test the validity of such a procedure. To do this a set of numbers was chosen from a set of normal random numbers and designated as growth rates. A second group of random numbers was chosen and designated as temperature indices. These two sets of unrelated numbers produced a typical scatter diagram when plotted. However, when accumulated, these data produced almost a perfect positive correlation. This procedure was tried with several sets of such data and in each case similar results were obtained. By accumulating data in this manner it was even possible to take two sets of data which had a negative correlation of $r = -1.0$ and change the slope of the line so that a perfect positive correlation was obtained. This should adequately demonstrate the fallacy in such a procedure. In any type of accumulation care should be exercised to assure that such a thing is not occurring with the data, otherwise erroneous conclusions may be drawn.

The problem of winter heaving of soil from an agronomic standpoint is most serious in seedling stands of small grains or forage crops. Under these conditions the soil is still relatively loose from the recent seedbed preparation and is subject to more heaving than a soil which has become well settled such as an old stand of alfalfa. However, such crops as ladino clover, which has a relatively shallow root system and which has most of its food reserves stored in large stolons lying on the surface of the soil, are also extremely susceptible to winter heaving. This may be even more serious in old established ladino clover stands than in younger ones.

The results thus far from the heaving studies point to the fact that good fall growth is perhaps the best insurance against winter injury to ladino. The uniformity of growth, and consequently ground cover, appears to be as important as the degree or amount of cover. In addition to reducing the amount of heaving good fall growth is an insurance against weak plants which are unable to survive winter heaving. A corrective measure of possible benefit in fields showing extensive heaving would be the rolling of fields either in late winter or early spring to push the heaved stolons back to the soil surface and thus minimize the injury from drying winds.

More information is needed on the interrelationship of light with other environmental factors. This may be extremely important in a grass-legume association. On clear days with light intensities of 10,000 foot-candles the intensity in the lower levels may be 150 foot-candles or less. This may very well be a contributing factor in the elimination of ladino clover from thick, tall grass stands. This is perhaps indicative of the need for cooperative effort between the agricultural climatologist and plant breeder to develop plants which will thrive under lower light intensities. Sprague, Robinson, and Garber (79) report a marked difference in the ability of various ladino clover clones to grow under reduced light intensities. Some clones survived and grew well for three months under low light intensities, while others were unable to live more than three weeks.

Continuous light studies were not made in this problem and the sampling data obtained will be discussed along with the temperature sampling data. It was felt that if a sampling scheme were devised to give an accurate measure of the light reaching the various levels within different types of forage a study could be set up to sample continuous light intensities at any level within the herbage. This could be done by periodically sampling the light readings at the various levels throughout the growth of the forage and by obtaining the ratio of the readings to those of full sunlight a continuous record of the amount of light reaching any given level could be rather accurately calculated.

A search of the literature disclosed no work dealing with sampling errors involved in microclimatic studies. It was felt that such a study was necessary to determine how accurately a single point within a given area actually measures the temperature for that area. The study of sampling errors was confined to measurements of heaving, temperature, and light.

Because of mechanical reasons it was necessary to use a systematic sample in making the heaving measurements. In doing this it was realized that when systematic sampling is used the sampling errors may be difficult to estimate. Since periodic variation may have occurred in the plots used in this experiment, as a result of seeding, harvesting methods, or growth conditions, systematic sampling may very well have given a biased estimate of the sampling error. However, by handling the data as indicated in formula (J) some of the limitations of systematic sampling were reduced. By processing the data in this manner the experimental errors obtained were more reliable, since the effect of correlation between individual peg measurements was essentially eliminated. The large variation found in two of the orchard grass plots explains in part the reasons for relatively large amounts of winter heaving of ladino clover when grown with this crop. It appears to be closely associated with irregularly distributed clumps of orchard grass.

A stratified random sampling scheme was chosen to sample temperature and light measurements to eliminate any possible periodic variation in the stand as a result of seeding methods, etc. The standard error involved in soil surface temperature measurements was very small, being less than one for all samples made. As the uniformity of cover increased, the accuracy of soil temperature measurements also increased. These data demonstrate that one location within plots of this size is adequate for reliable temperature measurements. This was true for both soil and air temperatures. When the orchard grass was 18 to 20 inches high the smallest standard error was obtained for the soil surface temperatures, with the next smallest at the 12-inch air level. The largest variation was found at the 3-inch air level. This is as expected since the greatest variation in density of plant growth occurs at this level. Such data should be of benefit in planning future experiments of this nature.

The differences found between temperature readings inside and outside of a standard Weather Bureau shelter may not be of import for most studies involving plants. However, it should be realized that rather large differences in these temperatures may exist and that interpretation of data should be made in light of these facts. This would be extremely important when responses to small differences in temperatures are to be measured.

Somewhat larger errors were involved in obtaining illumination data, with relative standard errors as high as 24.3 per cent being obtained. In order to reduce the standard error to an acceptable point, three to four times as many samples would have to be taken in each plot under these sampling conditions. The sampling error could be reduced through the establishment of a stationary illumination recorder to measure full sky radiation since some error undoubtedly resulted through failure to have the selenium cell exactly horizontal to the zenith of the sky.

Evaporation data collected served to demonstrate the extent to which such factors as wind speed, vapor pressure deficit, sunlight, temperature, and height of plant cover affected water loss. Essentially no differences in evaporation rates measured under various types of plant cover were noted. However, it must be realized that evaporation from a free water surface or from a porous atmometer bulb surface may be extremely different from the evaporation from a leaf surface. In addition to this limitation atmometer bulbs readily collect dust, pollen, and other foreign matter which reduces their reliability. For these reasons atmometer bulbs are not considered an accurate measure of plant water loss.

SUMMARY

The interrelationship of weather to yields and stand survival of ladino clover was reviewed. An attempt was made to characterize and to discuss some of the factors responsible for loss of ladino clover stands. Amounts and distribution of rainfall, extent and uniformity of fall growth, severity of winter heaving, and disease incidence appear to be extremely important factors. The precipitation pattern and its effect on soil moisture plays an important role in the growth of ladino clover and consequently its ability to survive adverse winter and early spring conditions.

Various methods of relating early spring growth of several forage species were compared. Both macro- and microclimatic temperatures were considered. In these studies leaf elongation was used as a criterion of growth. A close relationship was found between leaf elongation and actual dry matter production of Kentucky bluegrass. These data were only for the early spring growth period. The temperatures necessary for growth initiation in the spring and the "heat units" required for each increased increment of growth were studied. A mathematical formula was developed for calculating temperature-growth indices. Values obtained in this manner were compared with other methods of temperature presentation. All methods gave close relationship between temperature and growth rates for the early period of growth. Temperature appeared to be the one factor most

limiting growth.

The degree-day accumulation method of presenting temperature-growth data was compared with a method whereby weekly growth rates and weekly temperature indices were related. Data were presented to show that degree-day accumulation is a fallacious method to use in relating temperature and growth.

A limited study was made of the temperature variation found at different levels within different types of plant cover. In studying the sampling error it was found that one observation in a 3- by 18-foot plot was adequate for obtaining temperature measurements. The largest sampling errors were found at the 3-inch air level. The smallest sampling error was found for soil temperatures except on those plots where uneven plant coverage was present. These values were only slightly affected by height and type of plant cover.

Air temperatures measured inside and outside of a standard Weather Bureau shelter were compared. When average wind speeds were less than one mile per hour, differences as large as 10° F. were observed. However, no difference was found at average wind speeds of three or more miles per hour.

A scheme for transforming continuous full sunlight readings into light readings within the plant herbage was proposed. The ratio of light readings in the herbage to full sunlight was used in place of absolute values. Sampling errors involved in light measurements were much larger than those obtained for temperature measurements. If the same precision is to be obtained as with temperature sampling, smaller strata and a larger number of samples must be taken.

Amounts of winter heaving were measured by obtaining the upward movement of wooden doweling placed in the plot area. Variation in diameter of these pegs appeared not to be significant but the depth at which the pegs were driven made considerable difference. The uniformity of plant cover appeared to be more important than the amount or type of plant cover in reducing heaving damage. Frequent freezing and thawing appeared to be more destructive than longer cold periods when the soil remained frozen.

Evaporation rates were measured within various types of forage plant growth and at several heights within each. Spherical atmometer bulbs placed in the herbage were used for these measurements. Wind speed and vapor pressure deficits were the most important factors controlling evaporation rates. Very little difference was found in the amount of water lost from atmometer bulbs placed in plots of different forage species.

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