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BY

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ABSTRACT

EVALUATION OF PROBLEMS IN THE IMPROVEMENT OF GRASS PASTURES BY SOD SEEDING

BY

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Grass pastures without nitrogen fertilization are more productive when the sward contains a nitrogen fixing legume. The introduction of forage legumes into grass swards is generally most successful when the sod is plowed and tilled. In areas that are erosive or too steep to till, improving pastures by sod seeding is a satisfactory alternative. Difficulties in establishing a good stand of legumes are often encountered when sod seeding.

Four specific problems investigated were: First, low-pH soils and the effects of surface-applied lime when sod seeding alfalfa;, second, the killing of legume seedlings in the field by early spring freezing temperatures and cold hardiness of three legume seedlings under controlled conditions; third, grass suppression by cutting to simulate grazing compared to a herbicide in establishing two legumes in a sod and; fourth, effects of fertilizer on seedling survival when placed in contact with legume seeds under controlled conditions.

Equally as much alfalfa was produced when lime was broadcast on the surface at the rate of 11.2 t ha^{-1} or incorporated into the plow layer as recommended. No differences in stand density were obtained in three of four trials when lime at this high rate was surface applied or incorporated. Nitrogen fixation occurred only in areas of the low-pH soil where surface-applied lime had penetrated.

Trefoil stands were similar but alfalfa stands were consistently poorer when broadcast on 15 Mar. compared to 15 Apr. Freezing temperatures after March seedings killed many alfalfa seedlings. Greenhouse data indicated the LT_{50} for 2.3 hours of freezing as follows: alfalfa, -4.44 C > red clover, -5.39 C > and trefoil, -6.67 C.

Suppression of sown grasses by defoliation was as effective as a herbicide in legume establishment. Four cuttings after seeding suppressed grass competition more consistently than a herbicide. Quackgrass sods required a herbicide for adequate suppression.

Phosphorus in contact with legume seeds reduced seedling survival more severely than similar rates of K. Extremely low fertilizer-band pH caused low seedling survival with P. Potassium in contact with seeds did not reduce stands at rates less than 34.5 kg ha^{-1}.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

TABLE Page

CHAPTER 4

LIST OF FIGURES

FIGURE Page

CHAPTER 2

CHAPTER 4

INTRODUCTION

Production of many permanent pastures in the United States and in the entire world is limited because of a lack of adequate legumes in the sward. Kentucky bluegrass and other low producing grasses are an integral part of many forage programs, particularly in the North Central and Northeastern United States. For many years efforts have been made to improve production of these pastures through pasture renovation ranging from improved and increased fertilizer applications and better grazing management to a complete killing of the existing sod by tillage to enable legumes and more productive grasses to be established.

Over the last 50 years, an improvement in productivity of a pasture by any cultural practice has been known as a regeneration or renovation procedure. Graber (1936) worked extensively in improving unproductive pastures which he first called pasture renovation and described it as the establishment of dry weather legumes in grass sods without plowing. Pasture renovation is defined by the Crop Science Society of America as "the improvement of a pasture by the partial or complete destruction of the sod, plus liming, fertilizing, seeding, and weed control as may be required to establish desirable forage plants" (Decker et al., 1973). With the development in recent years of suitable chemical herbicides, pasture renovation has become known more generally as the establishment or re-establishment of high yielding and well-adapted legumes or grasses in an existing sward without completely destroying the sod.

The introduction of high-yielding forage legumes into less-productive grass swards by drilling the seed into the sod with a grain drill or other specialized equipment is now commonly referred to as sod seeding (White, 1966; Decker et al., 1969; Olsen et al., 1981). The broadcast application of legume seeds on the surface of grass sods has also become included in this generalized description of sod seeding (Tesar, 1980). While pasture renovation is understood to be the improvement of pastures by any method, including plowing and tilling, it is used synonymously throughout this study with sod seeding to refer to the introduction of forage legumes into a grass sward by drilling the seed in the sod or broadcasting it on the surface.

Plowing and field cultivation has been the most traditional, and considered the best method for re-establishing unproductive pastures, particularly when there has been no consideration for the cost of establishment or interruption to production. This method has been a more conventional and assured way of gaining a good stand (Roberts, 1960; Smith, 1975; Tesar and Hildebrand, 1975). There are, however, many areas that are too steep for plowing or too rough for conventional cultivating and seeding machinery. Renovation is particularly suited to the steeper slopes and to soils more susceptible to erosion where exposure of the bare soil surface is not desirable. Smith (1975) states that the problem of weed control in sod seedings makes this a less desirable method of pasture renovation than plowing and complete seedbed preparation. Better stands, higher seeding year yields (Scholl et al., 1970), and less work in establishing good stands are a result of plowing and seeding into a prepared seedbed, compared to renovation by surface cultivation (Smith, 1975). Other problems have been observed in making successful sod seedings into pastures in Michigan.

Many areas in need of pasture improvement are too steep and erosive for row crops and often have soils with pH values too low for alfalfa, the only permanent legume adapted to droughty soils. According to present recommendations, lime must be incorporated into the plow layer if soil pH is to be increased satisfactorily (Christenson et al., 1981). This is not possible without tillage and it is not known how successful broadcast applications of lime on the surface would be in reducing soil acidity sufficiently for successful sod seedings of alfalfa.

Adequate moisture is essential for good germination and early growth of legumes sod seeded into grass swards. This is especially crucial for seeds broadcast on the surface. The most successful sod seedings have been made in early spring where moisture from spring rains has been the most abundant (Taylor, et al., 1969; Tesar, 1980).

"Frost seeding" is the broadcasting of forage legume seeds on the surface early in the spring while the ground is still frozen. The movement of the soil from alternate freezing and thawing has helped to cover seeds and benefit germination. It is not known, however, how much the early spring freezing temperatures reduce germination and seedling survival. Even though temperatures may have been high enough for germination of introduced legume seeds, stands may be depleted by subsequent freezing periods. The extent or duration of freezing temperatures low enough to kill forage legume seedlings is also not known.

Adequate moisture to germinate sod-seeded legumes is the most important factor for successful stands. Almost as important is the reduction of competition from the grass sward to the inter-seeded species. This has been achieved in many different ways such as close grazing, burning, disking, field cultivating, and the use of herbicides, all with varying degrees of success. Unfortunately, the most successful suppression methods by herbicides and complete tillage to kill existing grasses have also been the most costly.

Grasslands most often involve herbivore animals that could be utilized in the reduction of inter-species competition by grazing the sod-seeded areas. Several researchers (Roberts, 1910; Love, 1944; Cullen, 1970) have described sod seedings where the grass competition was reduced by grazing. Comparisons of grazing with other methods of grass suppression have not been reported in the literature. It is not known if grazing of grasses in an inter-seeded pasture is as effective as herbicides in reducing competition for good legume establishment.

Considerable research reported shows the value of added fertilizer for early vigorous growth of seedlings (Brown, 1959; Tesar et al., 1954; Sheard et al., 1971). The greatest benefit has been from the placement of fertilizer in bands below the seeds where developing tap roots of legume seedlings utilize the phosphorous within two weeks (Tesar et al., 1954). Fertilization of seedings drilled in the sod has frequently been with the seed and fertilizer being placed together in contact in the same slit in the sod. The firm sod of the grasses in sod-seeded areas and the impracticality of machinery placing fertilizer under seeds in a sod have precluded separate placement.

Injury to germinating seeds placed in contact with fertilizer has been studied in many crops, but not in forage legumes. Injury would have to be considerable to be noticeable in stands in the field. Prior to this study it was not known which rates and concentrations of phosphorus and potassium in contact with forage legume seeds would be beneficial without being toxic to the seedlings.

Sod seedings require better management than seedings in a prepared seedbed because of additional difficulties encountered in precise depth placement of seed. In some cases, control of insects and snails in the sod are essential for good stands (Kalmbacher et al., 1979; Holland and Tesar, 1980).

The primary objective of this study was to investigate some of the problems encountered when making sod seedings of forage legumes into various grass sods. Specific objectives were to (1) evaluate the effects of surface-applied lime on an acid soil when sod seeding alfalfa; (2) compare forage legume seedling survival at various freezing temperatures; (3) compare low-cost simulated grazing of grass competition with a recommended herbicide when sod seeding; and (4) determine at what level phosphorus and potassium become toxic to seedlings when placed in contact with the legume seeds.

CHAPTER 1

EFFECTIVENESS OF SURFACE-APPLIED LIME ON ACID SOILS WHEN SOD SEEDING ALFALFA *(MEDICAGO SATIVA L.)*

ABSTRACT

Many areas of unproductive pastureland could be improved with the introduction of forage legumes into the existing grass sod. Pastures have often been grown in areas that have erodible and acidic soils, frequently droughty and usually not considered suitable for row crops. Seeding alfalfa *(Medicago sativa L.)* the only drought-resistant, long-lived legume adapted to these soils has generally not been successful in low pH soils. Recommendations state that lime must be incorporated into the plow layer to reduce soil acidity for good alfalfa growth. In this study alfalfa was grown on acid soils to determine the effectiveness of lime broadcast on the surface either before or after seeding compared to lime incorporated into the plow layer. Equally as much forage was produced when lime was broadcast at 11.2 t ha^{-1} on the surface or incorporated into the plow layer as presently recommended. No differences in stand density were obtained in three of the four trials when lime at this high rate was either surface applied or incorporated into the plow layer. Alfalfa

grown with lime broadcast at 2.8 t ha^{-1} produced better yields in comparison to no lime only on soils below pH 5.0. On soils of higher pH yields were equally as good when lime was broadcast at 0 or 2.8 t ha^{-1}. Lime at 2.8 t ha^{-1} on the surface after seeding alfalfa into a soil of pH 5.94 increased stand density but not yields. At this low rate of surface-applied lime, stand establishment was better when alfalfa was seeded into an untilled sod but not in a plowed and prepared seedbed.

Nitrogen fixation, determined by acetylene reduction, occurred only in areas of the soil where lime had penetrated adequately to reduce the acidity. The quantity of nitrogen fixed was not well correlated with soil pH and decreased with high exchangeable soil Al but increased proportionately with added lime.

Additional index words: pasture renovation, glyphosate, lime incorporation, acidic soils, aluminum toxicity, acetylene reduction.

INTRODUCTION

Grasslands occupy about one-half the total land area of the 48 contiguous states (Sprague, 1974). This is more than that utilized by all other crops combined, yet this area, according to the American Forage and Grassland Council (1974), is producing less than 25% of its potential. Yields of pastures and grassy hayfields in Michigan were shown to be easily doubled or tripled by the establishment of productive legumes in them (Tesar, 1975). Wedin et al. (1965) reported that yields of mixtures of grass with 30 to 40% legumes were equivalent to pure grass stands heavily fertilized with nitrogen. In the eastern humid region more than 75% of the pastures are located on land too steep for conventional tillage which is essential for complete pasture renovation (USDA, 1971). Sod seeding is the introduction of a legume (or grass) into a suppressed sod without tillage and is an attractive alternative to conventional methods of pasture establishment, particularly where there are hills and slopes where it is impractical or conservationally unwise to plow and prepare a seedbed.

This method, however, has not been without problems. The suppressed sod has on many occasions harbored insects and slugs that damaged or destroyed introduced seedlings (Braithwate et al., 1958; Kalmbacher et al., 1979; Holland and Tesar, 1980). Difficulties have also been encountered in not being able to place the introduced legume seed into the soil through the sod of heavily rooted grasses

(Holland and Tesar, 1982). Further problems have also been encountered when sod seedings have been made on soils of a low pH or during months when rainfall was not optimum (Holland, 1980).

Considerable work has shown the essentiality of incorporating agricultural limestone into the plow layer for maximum benefit to alfalfa, an acid-sensitive forage legume (Weidemann, 1936; Longenecker and Merkle, 1952; Hourigan et al., 1961). When the liming materials were not incorporated by tillage, penetration was relatively slow. Brown et al. (1956) applied 4.6 and 13.8 metric tons of lime per hectare to the surface of a grass sod and measured the pH with depth over a ten-year period. These researchers found that the rate of lime had less effect on pH adjustment than time. Their work indicated that it may take as long as 10 years to neutralize the plow layer. A similar study by Longenecker and Sprague (1940) showed that lime penetration was dependent on soil type and time.

Acid soils provide an unfavorable environment for most legumes, and low pH soils, without a calcareous sublayer, often contain high levels of toxic aluminum (Al). Buss et al. (1975) demonstrated that alfalfa cultivars have a narrower range of acid tolerance than other crops while Al has been shown to be the principal cause of poor growth in low pH soils (Foy and Brown, 1964; Kamprath, 1970). Munns and Fox (1976) showed that alfalfa growth increased relatively more by the adjustment of pH from 5.5 to 6.0 than within the ranges of 5.0 to 5.5 and 6.0 to 6.5. Coleman et al. (1959) determined that Al saturation was reduced to less than 10% of saturation in several soils by increasing the pH to 5.6.

Alfalfa produces the best yields on near-neutral soils.

Nodulation and nitrogen fixation are greatly enhanced by favorable soil conditions. Sod seeding of forage legumes is the most practical and conservationally sound method of pasture improvement on erodible slopes and hillsides. Frequently the soils in these areas are too acid to sustain a good stand of alfalfa. This study was instigated to: (1) compare alfalfa stand establishment, relative forage yield, and soil pH changes when agricultural limestone was broadcast on the surface or incorporated, as presently recommended, into the plow layer of acid soils; and (2) determine the relationship, if any, between the soil depth at which nitrogen fixation occurs on alfalfa grown in an acid soil and lime surface applied or incorporated into the plow layer.

MATERIALS AND METHODS

Four field experiments were established at two locations on three different acid soils.

Experiment 1. This study was conducted on a Kalamazoo sandy loam (fine-loamy over sandy mixed, mesic Typic Hapludalfs) soil of pH 4.8. Treatments were replicated four times in a split-plot, randomized, complete block design. Alfalfa was clear seeded at 9 kg ha^{-1} in the spring of 1978 after the area was plowed and fertilized with 45 kg P ha^{-1}. Prior to plowing, 5.6 t ha^{-1} of agricultural limestone was broadcast on the check treatments with an additional 5.6 t ha^{-1} added after plowing. This was incorporated by disking to a depth of 10 cm into the tilled surface. The rate of 11.2 t ha^{-1} is the maximum rate of lime recommended for application in one year on Michigan soils and is similar to recommended amounts in other North Central states (Warncke and Christenson, 1980). Other treatment blocks received 0, 2.8 and 11.2 tons of lime per hectare broadcast on the surface after seeding the alfalfa. Recommended levels of P and K fertilizer were applied annually.

Stand density was determined six weeks after seeding by counting alfalfa seedlings in four directed, 35-cm quadrat samples from each plot. Soil samples were obtained to a depth of 30 cm in five increments (0-2.5, 2.5-5, 5-10, 10-20, 20-30 cm), four months after seeding, and in each subsequent year. Soil pH was determined from these samples by using a 1:1 soil/water ratio. Four additional soil samples were also obtained at 15-cm increments below the 30-cm level and analyzed for pH, total acidic and exchangeable aluminum. To determine total acidic soil Al, samples were extracted with 1N NH_4OAc (pH 4.8) and analyzed by Directly Coupled Plasma Emission (DCPE). Exchangeable Al was determined by 1N KCl extraction and analyzed by the same DCPE. One forage harvest was made in the year of seeding and three in each succeeding year. Prior to each harvest percent alfalfa growing in each plot was estimated visually and these figures were used to calculate legume yield. Harvests were made from a 0.9 x 9.1 m area with a self-propelled, direct-chop harvester. A 1 kg forage sample from selected plots was dried with forced air at 65 C for 48 hours and used to determine dry matter. All yield data are reported in dry matter t ha^{-1} of the legume portion of the total forage yield.

Experiment 2. This trial was established on a Miami sandy loam (fine-loamy, mixed, mesic Typic Hapludalfs) soil of pH 5.3 and differed from Exp. 1 only in location, soil type, and initial soil pH. All data were obtained in an identical manner on similar dates and reported as in Exp. 1.

Experiment 3. This trial was seeded on a Hillsdale sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalfs) soil of pH 5.9 at the same location as Exp. 2. Treatments were replicated three times in a split-plot, complete block design. Fertilizer was not added at seeding but recommended levels were applied annually. A commercial grain-fertilizer drill wtih a small-seeded-legume box adapted to provide precision seed setting was used to sod seed alfalfa at 13.5 kg ha^{-1} in the spring of 1980 into a *N-(phosphonomethyl)glycine* (glyphosate)-suppressed quackgrass *(Agropyron repens L.)* sod. Lime at 0, 2.8, 5.6 and 11.2 t ha^{-1} was surface applied to designated blocks after seeding. Alfalfa stand density, annual yields, soil aluminum, and pH were evaluated in the same way as in Exp. 1.

Experiment 4. In the spring of 1981 alfalfa was sod seeded into a quackgrass-infested sward on a Kalamazoo sandy loam soil. Treatments were replicated four times in a split-plot complete block design. Fertilizer was not added at seeding but recommended levels were applied annually. The same commercial drill used in Exp. 3 was used to make all seedings, including those of the check plots in a prepared seedbed. Glyphosate was used in the fall of 1980 to suppress the grasses. During late fall prior to seeding the alfalfa, lime was broadcast on the surface of designated blocks at 0, 2.8, 5.6, and 11.2 t ha^{-1}. Check blocks received 5.6 t ha^{-1} before plowing and 5.6 t ha^{-1} incorporated into the tilled surface after plowing. Data were obtained similarly and reported as in the previous trials.

Acetylene reduction analysis as described by Hardy et al. (1968) was conducted on randomly selected plants prior to the final harvest in the fall of 1982. Replicated core samples 10 x 30 cm deep were obtained from all plots with each core sampled directly over one alfalfa crown. Samples were discarded where the tap root was not completely contained within the core. Each soil core containing the alfalfa root was divided at 2.5- and 5.0-cm depths and thereafter at 5.0-cm increments to a total depth of 30 cm. The lower five depths of the soil cores were each placed in a 1-L container and sealed with a metal lid equipped with a serum stopper. The first and second depths were sealed in 0.5-L containers so as to adjust for the smaller bulk quantity of these samples.

Ten percent of the atmosphere in each container was evacuated and replaced with calcium-carbide-generated acetylene. The samples were then incubated under a cover at ambient field conditions for one hour. All sampling was conducted between 0900 and 1200 hours to minimize variation due to diurnal fluctuations in the rate of nitrogen fixation. One ml of gas was withdrawn from each container at the end of the incubation period and analyzed on a gas chromatograph (Varian aerograph series 1400) with a flame ionization detector. Ethylene production rates were quantified by peak height and are expressed in micromoles sample^{-1} hour^{-1}.

Four controls were utilized to determine ethylene source: (1) complete samples (soil and roots) were assayed but did not have acetylene added; (2) plant samples (crowns and roots) without soil were treated similarly; (3) cores of soil without legume roots were segmented and assayed with quantities of acetylene added to each container; and (4) sealed empty assay vessels were treated as complete samples and a 10% atmospheric concentration of acetylene was added.

RESULTS AND DISCUSSION

Experiment 1, Kalamazoo sandy loam, pH 4.8: Alfalfa stand establishment was equally as good with lime surface applied at 11.2 t ha^{-1} or incorporated into the plow layer as presently recommended (Table 1). When lime was not added to this acid soil, fewer seedlings survived than when 11.2 t ha^{-1} was either broadcast on the surface or incorporated into the plow layer. Stand establishment was similar when lime was added at 0 or 2.8 t ha^{-1}. Seedling counts made six weeks after seeding indicated that lime at 2.8 t ha^{-1} was not adequate to neutralize the soil acidity for good germination. Soil samples taken four months after seeding indicated an insignificant change in pH at the 2.8 t ha^{-1} lime application rate (Fig. 1). In comparison, 11.2 t ha^{-1} of lime on the surface or incorporated decreased the surface soil acidity over the same period by 1.26 and 1.77 pH units, respectively.

There was no significant difference in total four-year yields of alfalfa on soil treated with 11.2 t ha^{-1} of lime broadcast or incorporated into the soil as recommended. Alfalfa grown where 0, 2.8, and 11.2 t ha^{-1} of lime was applied to the surface produced 42, 83, and 92%, respectively, of the alfalfa in soil with lime incorporated into the plow layer at 11.2 t ha^{-1}.

When the 11.2 t ha^{-1} lime application was split with one-half plowed under and the remainder surface applied and incorporated, noticeable pH changes occurred to a depth of 30 cm (Fig. 1). This would be more indicative as an effect of plowing depth rather than lime movement through the soil profile. When the same amount of lime was surface applied the pH in the surface 2.5 cm was nearly as high as when the lime was incorporated. The surface-applied lime at 11.2 t ha^{-1} did not appreciably increase the pH of the 2.5 to 5.0 cm depth in the year of application but in the third, fourth, and fifth years after application pH increased significantly from 4.7 to 5.5, 5.6, and 6.0, respectively. No significant changes occurred below 5 cm. At the lime application rate of 2.8 t ha^{-1} the pH of the surface 2.5 cm changed from 4.8 to 5.6 in two years in comparison to a pH change to 6.3 for 11.2 t ha^{-1} on the surface over the same period.

A decline over time in soil surface pH when the lime was incorporated was most likely due to lower lime concentration in the surface 2.5 cm and leaching of this lime through the tilled soil. When no lime was applied, the soil surface became slightly less acidic in the first two years. This most likely occurred as a result of additional plant and root growth from the introduced alfalfa crop.

Subsurface soil pH was extremely low (Fig. 5) and total soil acidic aluminum was very high (Fig. 6). Exchangeable aluminum was present in quantities sufficient to have a toxic effect on alfalfa and very likely was the limiting factor for good plant growth and production on the unlimed soil (Fig. 6).

Experiment 2, Miami sandy loam, pH 5.3: Alfalfa, with lime surface applied at 11.2 t ha^{-1}, produced as good yields over four years as when the same amount was incorporated into the plow layer and alfalfa stand establishment was equally good at all lime treatments (Table 2). The initial soil surface pH of 5.3 was 0.5 pH unit more alkaline than in Exp. 1 and would have contributed to the higher stand density and lack of treatment differences. Four-year yields of alfalfa when lime was surface applied at 11.2 t ha^{-1} were 14% higher than yields from treatments of 2.8 t ha^{-1} and 24% greater when no lime was added (Table 2). No yield increases were obtained with the addition of lime at 2.8 t ha^{-1}. In the first year after seeding (1979), however, yields were highest from the incorporated lime treatment. This may indicate an early, short-term advantage for this soil by incorporating the lime into the plow layer.

The pH of the surface 2.5 cm was higher in each of the four years with 11.2 t ha^{-1} of lime surface applied than when the lime was incorporated as recommended (Fig. 2). In the third, fourth, and fifth years after application of 11.2 t ha^{-1} on the surface pH of the 2.5 to 5.0 cm depth was increased from 5.1 to 6.3, 6.6, and 6.7, respectively. These pH values were equal in year three and higher in the last two years than when the lime was incorporated. There was a noticeable, but lesser improvement of pH in the 5 to 10 cm depth in the last three years with pH values in the fourth and fifth years (6.1 and 6.3) equalling those when the lime was incorporated. There was a slight increase in pH in the fourth and fifth years at the 10-20 cm depth indicating that lime applied on the surface at the recommended rate increased pH below 10 cm after three years.

When lime was surface applied at 2.8 t ha^{-1}, only four months were required to decrease the surface soil acidity 0.94 pH unit (Fig. 2). This was a five-fold greater change than that obtained over the same period from the addition of lime to the soil in Exp. 1 (Fig. 1). Higher initial pH (Fig. 2), less acidic subsoil (Fig. 5) and relatively very little soil aluminum (Fig. 6) all may have contributed to the more rapid decrease in acidity of this soil.

Sub-surface acidity decreased with depth indicating a calcareous sublayer (Fig. 5). Only traces of exchangeable soil Al were present and this was not great enough to cause plant toxicities (Fig. 6). The yearly decrease of the surface pH when lime was incorporated into the plow layer resulted from lower lime concentration per unit of soil and possible leaching in the disturbed profile.

Experiment 3, Hillsdale sandy loam, pH 5.9: Stand establishment was better at all levels of liming than with no lime (Table 3). Stands were 29, 52, and 69% better when lime was applied at rates of 2.8, 5.6, and 11.2 t ha^{-1}, respectively, than when no lime was applied. The stand was 31% better when lime was applied at 11.2 compared to 2.8 t ha^{-1}. These differences are particularly significant since the lime was not applied until after seeding and stand determinations were made ten weeks later. The soil had a relatively high initial pH (Fig. 3) but a definite benefit in seedling establishment was derived from the lime broadcast after seeding.

The surface-applied lime increased the pH appreciably in the surface 2.5 cm at all three levels of application and increases were similar but somewhat less at the 2.5 to 5.0 cm depth (Fig. 3). At the 5 to 10 cm depth, pH increases were not significant until the second and third years after application. Below 10 cm there was only a slight change in pH.

Alfalfa yield was equally as good in all years from limed or unlimed areas (Table 3). The alfalfa on this soil of pH 5.9 produced 23.2 t ha^{-1}, however, this was not significantly less than the 27.4 tons from alfalfa on the soil with lime surface applied at 11.2 t ha^{-1}. A high initial soil pH of 5.9 (Fig. 3), an extremely alkaline subsurface (Fig. 5), and negligible quantities of exchangeable soil aluminum (Fig. 6) likely contributed to the good yields from the unlimed plots. This agrees well with data from Rice et al. (1977) that showed relative yields of alfalfa increased with increasing soil pH to 6.0, and then became constant at higher pH levels.

Experiment 4, Kalamazoo sandy loam, pH 4.9: Stands were 66, 89, and 77% better when lime was broadcast on the surface at 2.8, 5.6, and 11.2 t ha^{-1}, respectively, than when no lime was applied (Table 4). Alfalfa, with lime incorporated into the plow layer at 11.2 t ha^{-1}, had a 16% greater stand density than when no lime was added.

Yields in the seeding year were low but equal following surface applications of lime at 2.8, 5.6, or 11.2 t ha^{-1}, but all were better than when no lime was applied. When the lime was incorporated into the plow layer, yields in the year of seeding were more than double the yields from any surface-applied treatment. In the year after seeding (1982), however, yields were high and equally good when lime at 11.2 t ha^{-1} was broadcast on the surface or incorporated into the plow layer. When lime was broadcast at 2.8 t ha^{-1}, alfalfa yield in the second year (1982) was 30% lower than when 11.2 t ha^{-1} was broadcast but almost five times greater than when no lime was applied. Surface application of lime at 5.6 and 11.2 t ha^{-1} increased yields

31 and 43% more, respectively, than yields obtained at the 2.8-ton level.

Within 12 months after broadcasting lime on the surface at 2.8, 5.6, and 11.2 t ha^{-1}, soil pH of the surface 2.5 cm was increased at all three levels from 5.0 to 6.4, 6.7, and 6.8, respectively (Fig. 4). When the recommended rate of 11.2 t ha^{-1} was incorporated the surface pH was only slightly higher (6.9) than from the same amount surface applied. The pH in the 2.5 to 5.0 and 5 to 10 cm depths, however, was greater in both years when the high rate of lime was incorporated but was much lower (5.8) in the second year when surface applied. This collective neutralization of the pH for the three surface-applied treatments would have helped produce the similar seeding year yields and lack of stand differences. The lime was applied six months prior to seeding and most likely weathered sufficiently to provide a more suitable seedling environment than the unlimed acidic soil.

The soil pH did not change significantly between the first and second year after liming (Fig. 4). In the same period, however, forage yields increased markedly as lime applications were increased to 11.2 t ha^{-1}. At this level, yields of alfalfa were similar regardless of whether the lime was surface applied or incorporated as recommended. Greenhouse studies with incremental lime rates incorporated into a similar Kalamazoo soil (Ross et al., 1964) produced proportionally comparable, but larger, yield increases. Low subsurface pH (Fig. 5) and toxic quantities of exchangeable soil Al (Fig. 6) most likely resulted in the lower yields associated with these low levels of lime. With increased calcium available from the higher lime rates, Al toxicity to the alfalfa would likely have been reduced and yields increased accordingly.

Acetylene reduction tests demonstrated distinct differences in atmospheric nitrogen fixation ability between alfalfa grown in areas of high and low lime rates (Fig. 7). When no lime was added to this acid soil, the alfalfa plants were small and produced relatively no ethylene. Alfalfa grown where lime was applied at 2.8 t ha^{-1} produced only small amounts of ethylene. When the lime rate was doubled to 5.6 t ha^{-1}, however, the ethylene produced by nodules in the surface 5 cm was more than four times greater. Alfalfa grown with lime surface applied at 11.2 t ha^{-1} produced almost eight times as much ethylene as alfalfa on soils limed with 2.8 t ha^{-1}. Only nodules growing at soil depths affected by the surface-applied lime produced a significant amount of ethylene. Difficulties in sampling the surface 2.5 cm may have caused the inconsistent ethylene production where lime was broadcast on the surface at 2.8 t ha^{-1}.

From the data presented, it appears that soil pH (Fig. 4) was not the only factor that affected alfalfa nodulation and, therefore, subsequent nitrogen fixation. Ethylene production (Fig. 7) did not correlate well with soil pH data presented in Fig. 4. Soil surface acidity was neutralized sufficiently for nodulation and growth even at the lowest lime rate. Alfalfa was shown by Munns (1970) not to nodulate below pH 4.8 even at high levels of calcium. At the same time he demonstrated that low levels of calcium (0.2 mM in solution) inhibited nodulation regardless of pH. Calcium was available in this acid soil in quantities ranging from 1000 kg ha^{-1} in the no lime treatments to 5000 kg ha^{-1} in the surface 2.5 cm when lime was broadcast on the surface at 11.2 t ha^{-1}. A combination of relatively lower quantities of available calcium from the various lime treatments and high levels of soil Al most likely prevented greater acetylene reduction at the lower liming rates. It is not known why ethylene production was comparatively low when lime was incorporated into the plow layer when the 2.5-cm surface layer had a pH of 6.7, equal to that where the lime was surface applied. Roots and nodules may have grown over a wider area of the less acidic soil profile and a lower percentage of nodules possibly was sampled within each soil core used for analysis. Webel et al. (1976) found that incorporation of lime provided a uniform distribution of alfalfa nodules throughout the root system, whereas broadcasting the lime on the surface resulted in a large cluster of nodules at the crown with very few nodules on the rest of the root system. Excellent stand establishment and yields from alfalfa when lime was incorporated indicated that nodulation and total nitrogen fixation was more than adequate.

In areas where plowing and tilling of the soil is not recommended because of the danger of erosion, greater productivity can be gained by introducing high yielding alfalfa. Surface application of lime applied at recommended rates in these experiments, even on extremely acid soils, reduced surface acidity sufficiently for good alfalfa stand establishment and subsequent yields, similar to those in a soil with lime incorporated into the tilled surface as recommended.

SUMMARY AND CONCLUSIONS

Four field experiments were conducted at two locations on three different low pH soils. Alfalfa was seeded into a tilled seedbed or drilled into a herbicide-suppressed sod. Lime was incorporated into the plow layer before seeding or broadcast on the surface without incorporation either before or after seeding.

Equally good stands and yields of alfalfa were produced in two experiments when lime was applied in the same quantity on the surface or incorporated into the plow layer. Surface-broadcast lime resulted in increased stand density on a relatively high pH soil even when applied after seeding, but yields were not increased. In the fourth trial, a better stand was obtained by incorporating the lime but yields were not different from those produced by alfalfa when the lime was broadcast on the surface. Subsoil pH levels were very low in the two trials that produced the poorest alfalfa yields when lime was not added. Potential toxic levels of exchangeable soil aluminum corresponded to the low pH of these areas. Greater quantities of lime were required to successfully grow alfalfa in the trials with high levels of exchangeable subsoil aluminum.

Significant nitrogen fixation occurred only at soil depths to which surface applied lime had penetrated or where lime was incorporated into the plow layer.

The data in these four experiments on acid soils indicate that alfalfa can be grown successfully on low pH soils with adequate amounts of lime surface applied to reduce acidity. Many existing unproductive grass pastures of low pH could be improved simply and economically by sod seeding alfalfa following an application of adequate amounts of lime broadcast on the surface of sods suppressed to permit alfalfa establishment.

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Table 1. Stand density and dry matter yield of alfalfa seeded into a tilled Kalamazoo sandy loam, pH 4.8, with various rates of lime surface applied after seeding or incorporated into the plow layer before seeding (Exp. 1).

Lime	Seedlings	Yield					
$t\ ha^{-1}$	m^{-2}	Seeding Year	1979	1980	1981	1982	4-yr Total
		$t\ ha^{-1}$					
0	162	1.7	3.0	4.0	8.2	7.0	22.2
2.8	169	2.3	9.2	11.8	12.5	10.6	44.0
11.2	189	3.3	10.7	12.9	13.0	12.3	48.9
11.2 (incorp)	207	2.5	12.5	13.7	13.6	13.2	53.0
$LSD_{0.05}$	25	0.5	1.2	2.0	1.5	1.6	5.5

Table 2. Stand density and dry matter yield of alfalfa seeded into a tilled Miami sandy loam, pH 5.3, with various rates of lime surface applied after seeding or incorporated into the plow layer before seeding (Exp. 2).

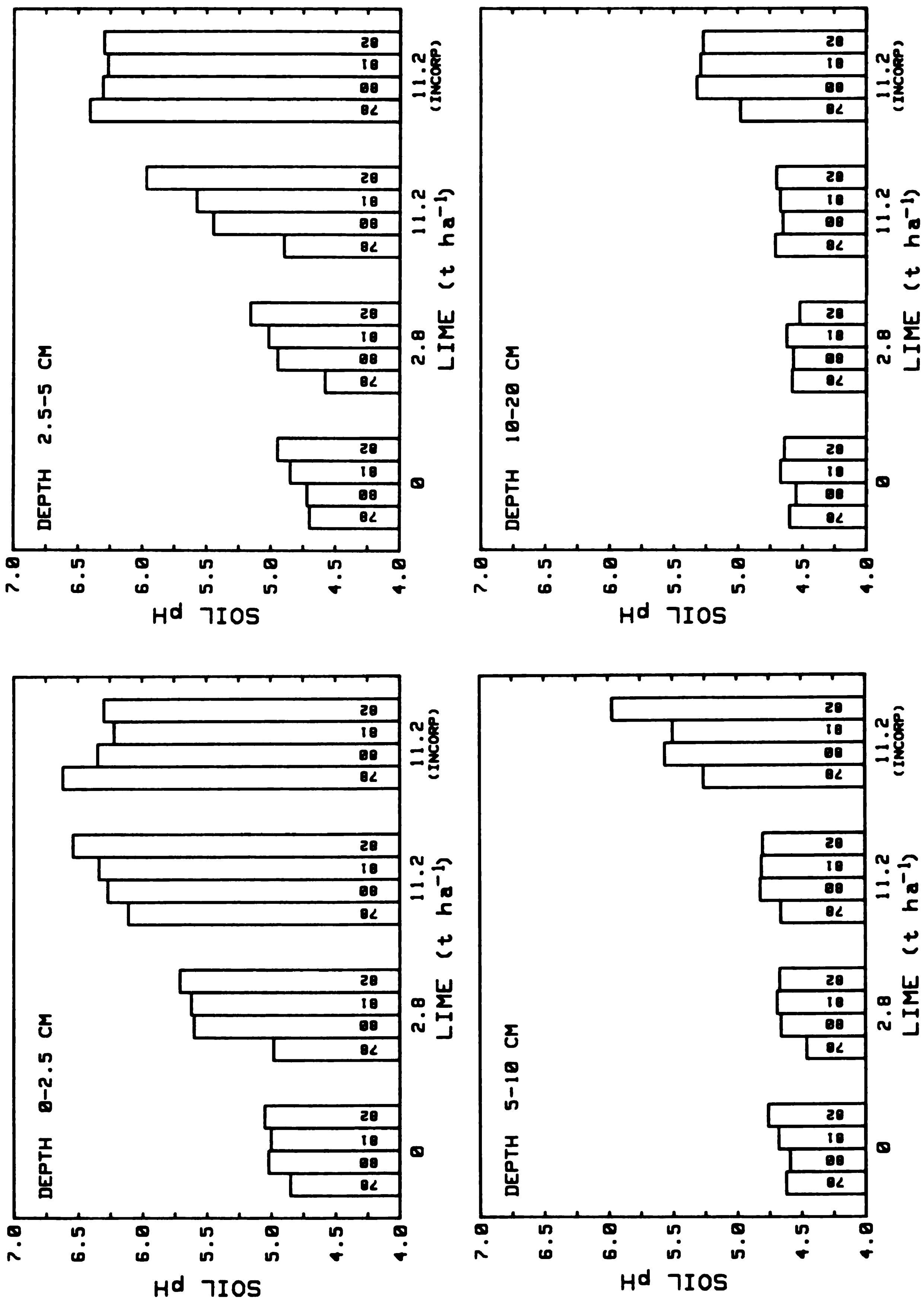
Lime	Seedlings	Yield					
t ha^{-1}	m^{-2}	Seeding Year	1979	1980	1981	1982	4-yr Total
		t ha^{-1}					
0	314	2.0	8.7	16.1	14.4	13.9	53.2
2.8	300	2.2	11.7	16.5	15.7	13.9	57.9
11.2	301	2.7	10.7	18.3	17.4	15.2	65.9
11.2 (incorp)	284	2.7	15.9	17.7	16.9	14.9	65.4
$LSD_{0.05}$	NS	NS	4.1	1.3	1.4	NS	7.0

Table 3. Stand density and dry matter yield of alfalfa sod seeded into a Hillsdale sandy loam, pH 5.9, with various rates of lime surface applied after seeding (Exp. 3).

Lime	Seedlings	Yield			
		Seeding			2-yr
t ha^{-1}	m^{-2}	Year	1981	1982	Total
		t ha^{-1}			
0	83	1.1	11.3	11.9	23.2
2.8	107	1.2	12.8	13.7	26.5
5.6	126	1.5	12.3	13.7	26.1
11.2	140	1.9	13.3	14.1	27.4
$LSD_{0.05}$	20	NS	NS	NS	NS

Table 4. Stand density and dry matter yield of alfalfa sod seeded into a Kalamazoo sandy loam, pH 4.9, with various rates of lime surface applied or incorporated into the plow layer before seeding (Exp. 4).

Lime	Seedlings	Yield	
t ha^{-1}	m^{-2}	Seeding Yr	1982
		t ha^{-1}	
0	61	0.2	1.5
2.8	101	1.3	7.2
5.6	115	1.5	9.4
11.2	108	1.5	10.3
11.2 (incorp)	254	3.2	11.8
$LSD_{0.05}$	37	0.5	1.6


DEPTH 0-2.5 CM
DEPTH 2.5-5 CM
DEPTH 5-10 CM
DEPTH 10-20 CM
SOIL pH
7.0
6.5
6.0
5.5
5.0
4.5
4.0
79
80
81
82
0
2.8
11.2
11.2
(INCORP)
LIME (t ha^{-1})

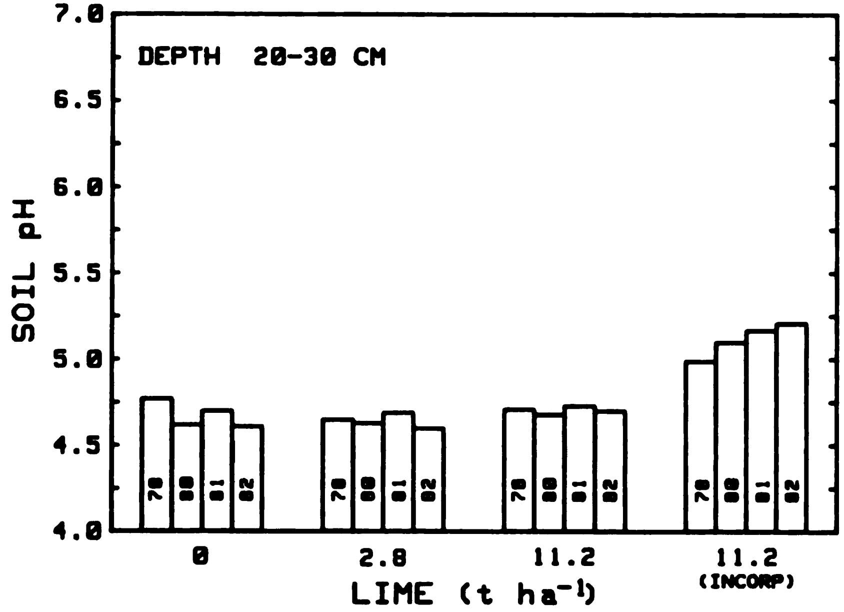
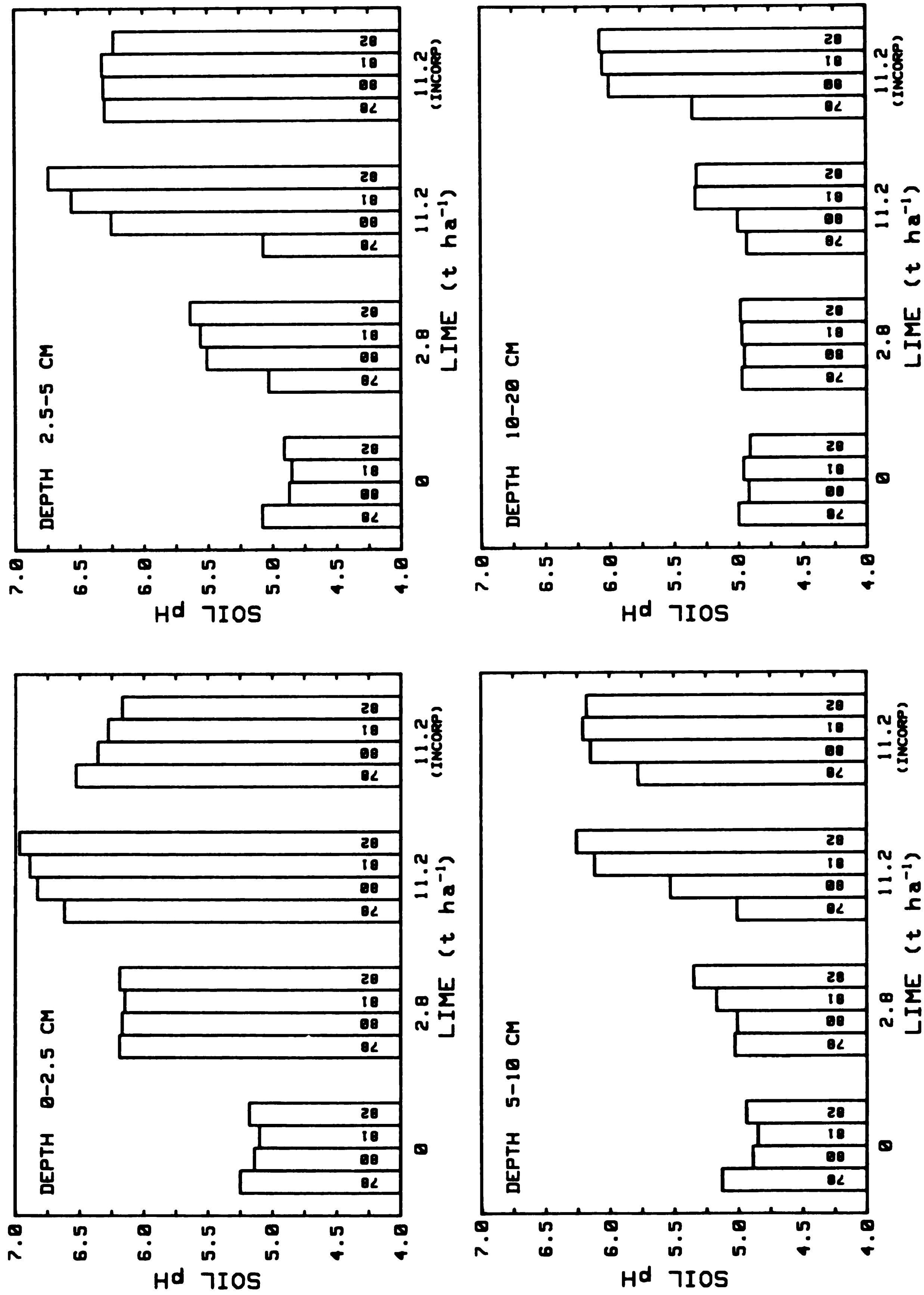


Fig. 1. Soil pH obtained in the fall of each year from five depths of a Kalamazoo sandy loam after lime was broadcast on the surface or incorporated into the plow layer (Exp. 1).


DEPTH 0-2.5 CM
DEPTH 2.5-5 CM
DEPTH 5-10 CM
DEPTH 10-20 CM
SOIL pH
LIME (t ha-1)
0
2.8
11.2
11.2 (INCORP)
78
80
81
82
7.0
6.5
6.0
5.5
5.0
4.5
4.0

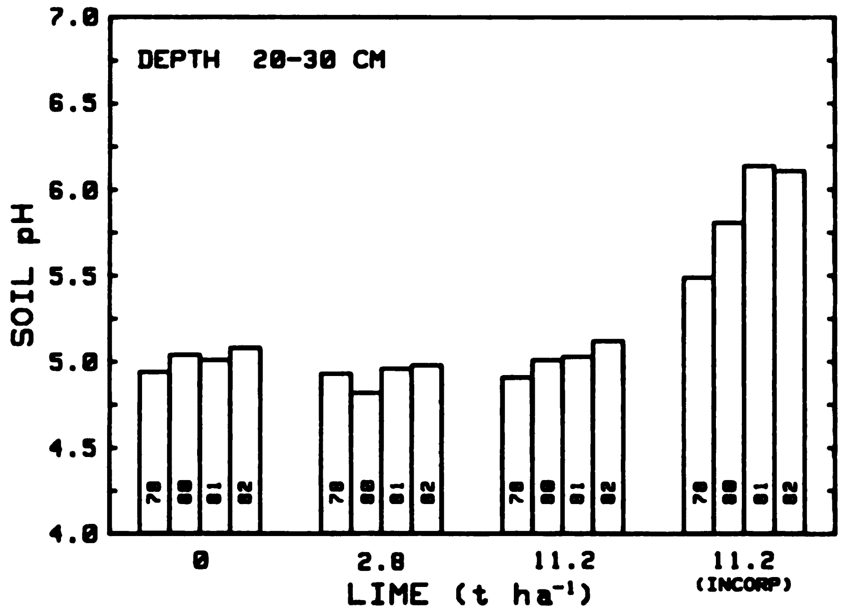
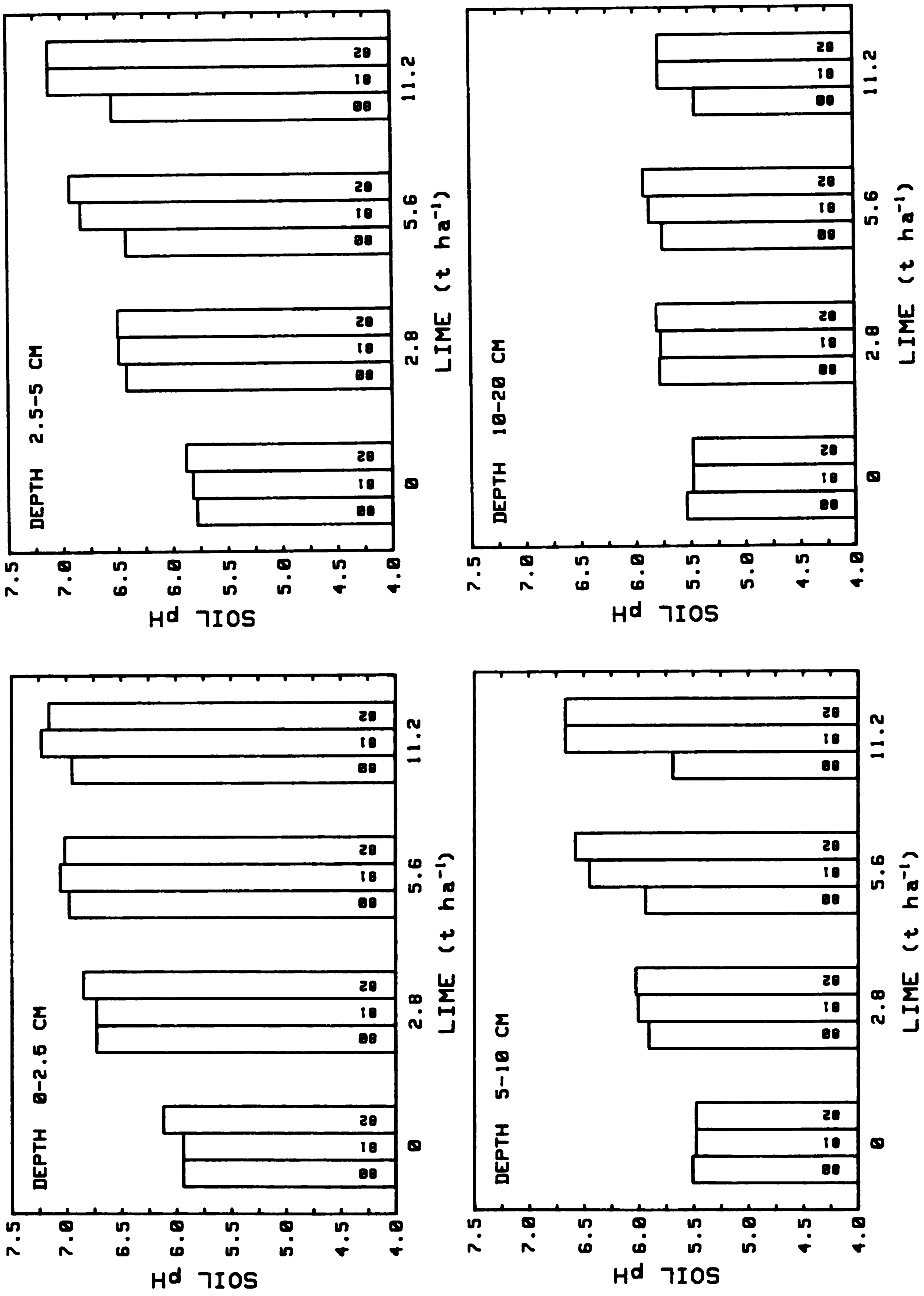


Fig. 2. Soil pH obtained in the fall of each year from five depths of a Miami sandy loam after lime was broadcast on the surface or incorporated into the plow layer (Exp. 2).


DEPTH 0-2.5 CM
DEPTH 2.5-5 CM
DEPTH 5-10 CM
DEPTH 10-20 CM
SOIL pH
LIME (t ha^{-1})
0
2.8
5.6
11.2
80
81
82
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5

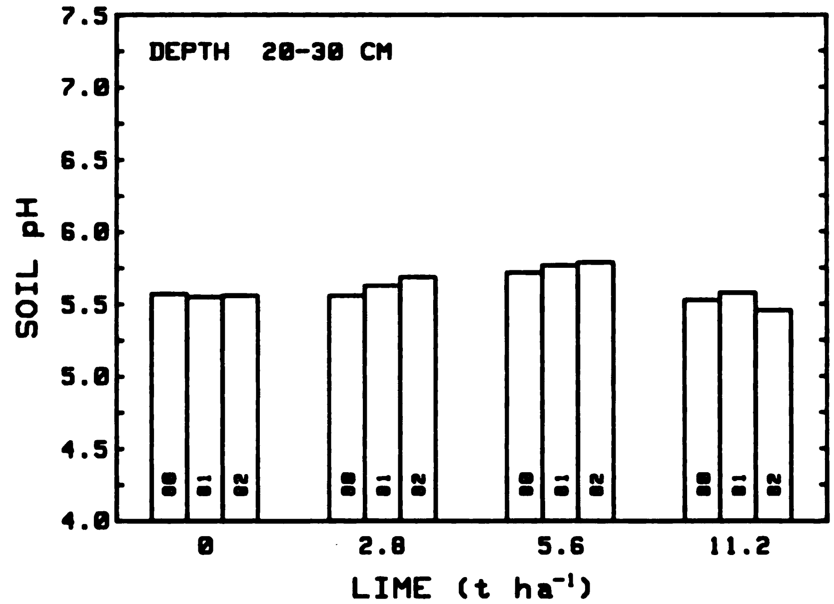


Fig. 3. Soil pH obtained in the fall of each year from five depths of a Hillsdale sandy loam after lime was broadcast on the surface or incorporated into the plow layer (Exp. 3).

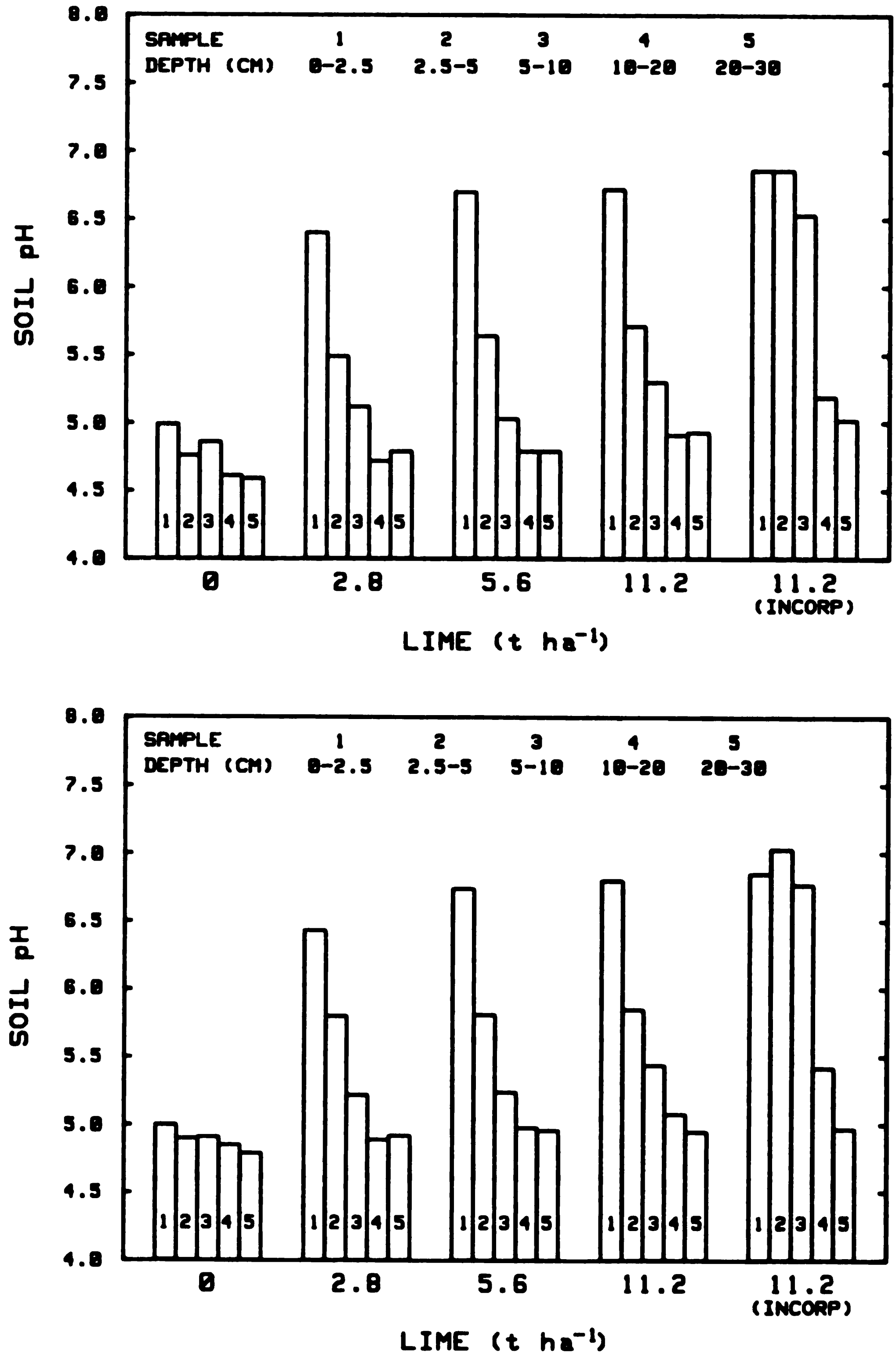


Fig. 4. Soil pH from five depths of a Kalamazoo sandy loam one (top) and two years (bottom) after lime was broadcast on the surface or incorporated into the plow layer (Exp. 4).

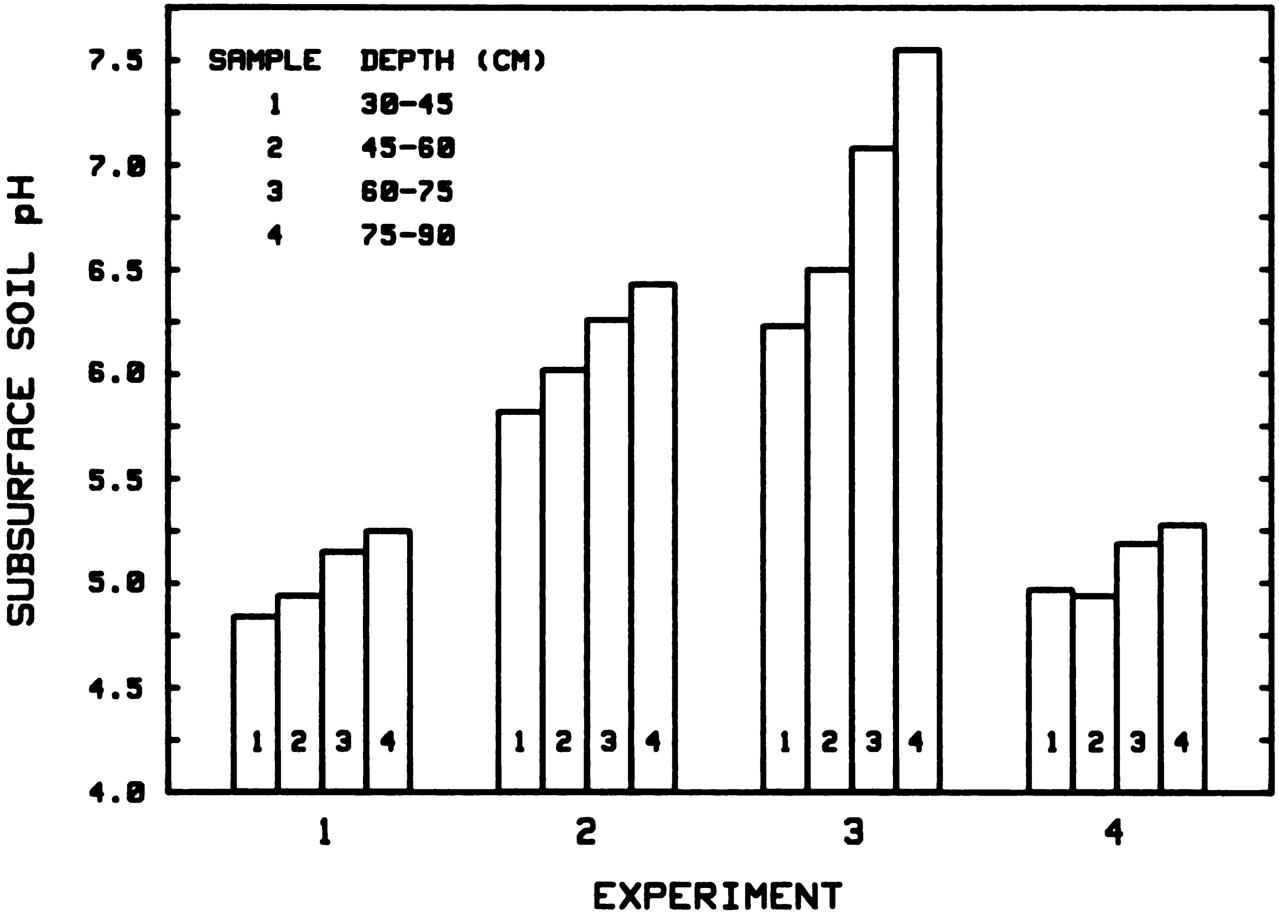


Fig. 5. Soil pH from four sub-surface levels of a Kalamazoo sandy loam (Exp. 1 and 4), Miami sandy loam (Exp. 2) and a Hillsdale sandy loam (Exp. 3).

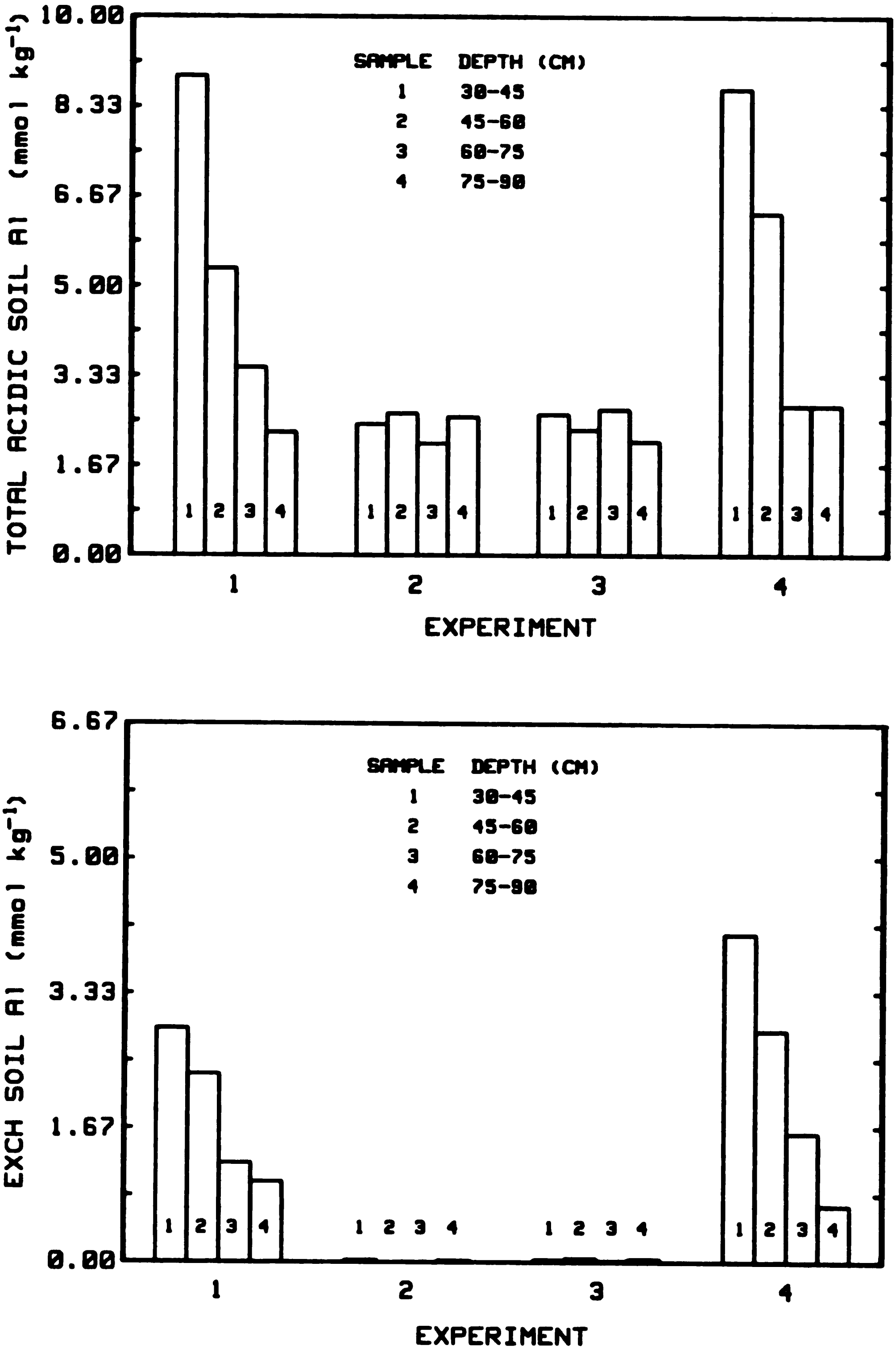


Fig. 6. Total (top) and exchangeable (bottom) soil aluminum from four sub-surface levels of a Kalamazoo sandy loam (Exp. 1 and 4), Miami sandy loam (Exp. 2) and a Hillsdale sandy loam (Exp. 3).

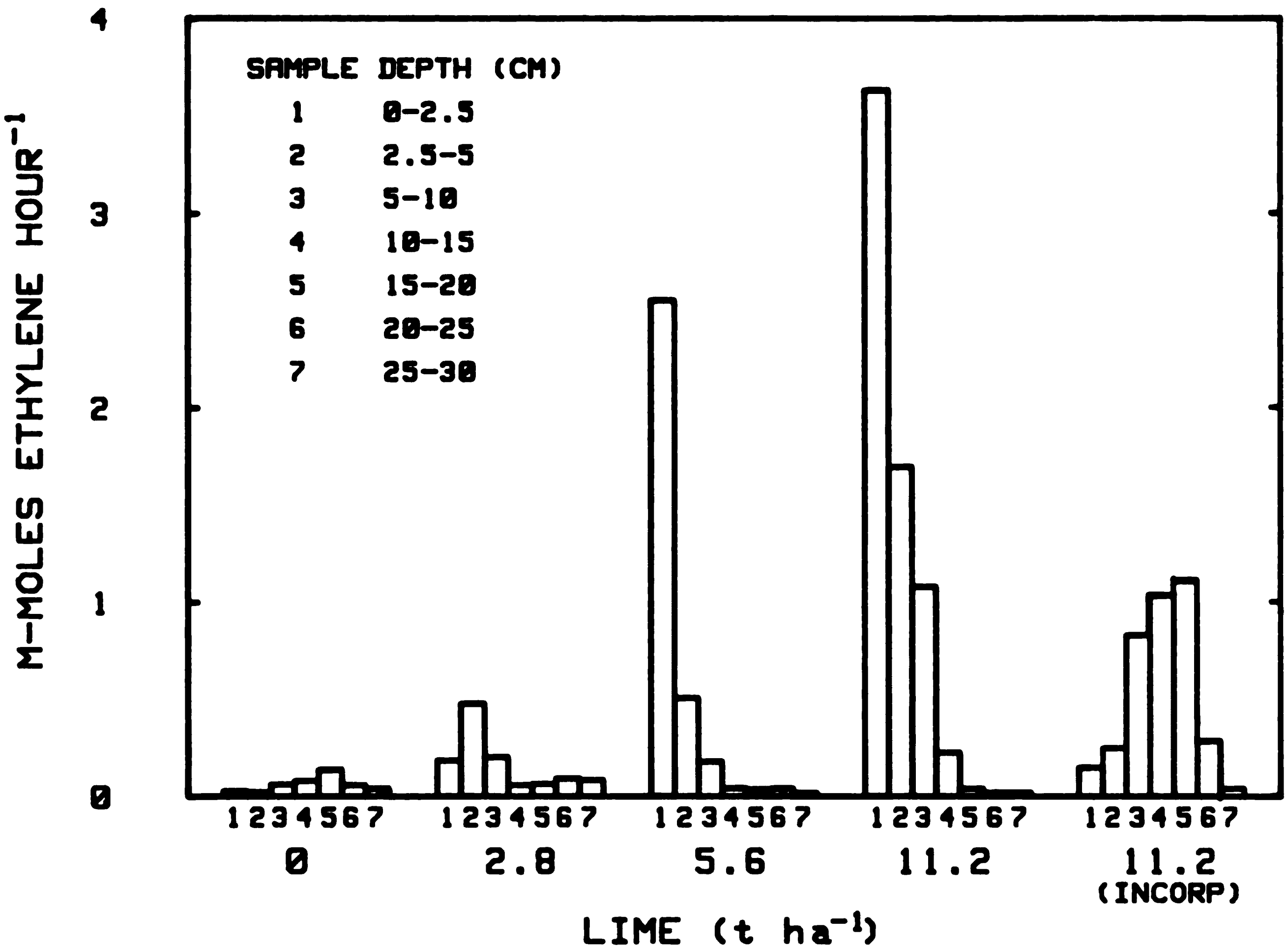


Fig. 7. Ethylene production from alfalfa grown on a Kalamazoo sandy loam soil, pH 4.9, and sampled two years after lime was broadcast on the surface or incorporated into the plow layer (Exp. 4).

CHAPTER 2

ESTABLISHMENT OF FORAGE LEGUMES AS INFLUENCED BY DATE AND METHOD OF SEEDING AND FREEZING TEMPERATURES

ABSTRACT

Sod seedings of forage legumes are most successful when made in early spring with adequate moisture and suitable warm temperatures. Producers have been encouraged to broadcast legume seeds on frozen ground so freezing and thawing in early spring would aid in seed coverage. With these early seedings it is not known how many seeds germinate and are killed by subsequent freezing periods.

Five field and one greenhouse/growth-chamber trial was conducted to determine the resistance of newly germinated alfalfa *(Medicago sativa L.)*, red clover *(Trifolium pratense L.)*, and birdsfoot trefoil *(Lotus corniculatus L.)* seedlings to sub-zero temperatures. In field experiments, alfalfa and trefoil were seeded by three methods—broadcast and drilled in a sod compared to band seeding in a prepared seedbed (check) on three spring dates—15 Mar., 15 Apr., and 15 May. Seedling counts and forage yields were used to evaluate stand establishment and freezing injury.

Alfalfa stands were consistently poorer when broadcast-seeded

on 15 Mar. compared to 15 Apr. but trefoil seedings were equally good when made on the same dates. Freezing temperatures in late March and early April likely injured alfalfa but not trefoil. Alfalfa and trefoil seedings broadcast in mid-April were satisfactory and seedling density approached drilled seedings made on the same date. Yields were generally highest from mid-April band and drilled seedings, intermediate when broadcast on 15 Mar. and 15 Apr., and lowest when broadcast on 15 May. Trefoil yields from 15-May-drilled seedings were similar to March and April broadcast seedings.

Under controlled conditions, alfalfa, red clover, and trefoil were hardened for 2, 4, or 6 days, and frozen for 1, 2, or 4 hours at -2.22, -3.33, -4.44, -5.56, or -6.67 C. Resistance to freezing injury was in the order of trefoil > red clover > alfalfa. Averaged freezing periods of 2.3 hours were lethal to 50% (LT_{50}) of alfalfa seedlings at -4.44 C, red clover at -5.39 C and trefoil at -6.67 C, corroborating freezing injury of seedlings in the field of alfalfa >> trefoil.

Additional index words: *Medicago sativa L.*, *Trifolium pratense L.*, *Lotus corniculatus L.*, sod seeding, frost seeding, cold resistance, stand depletion.

INTRODUCTION

Grassland production in humid climates is often limited by the supply of available nitrogen, but this may be overcome through the use of nitrogenous fertilizers or by growing legumes in association with the grasses. The practice of introducing legumes into an established grass sod has been commonly referred to as pasture renovation and is now also known as sod seeding. The advantages and problems associated with sod seeding have been studied by many researchers. As early as 1878 Roberts (1910) worked on pasture improvement at Cornell and later Graber (1928) introduced legumes into grass swards in Wisconsin. More recent studies have involved the use of chemicals to reduce grass competition (Blackmore, 1965; Sprague, 1960; Taylor et al., 1964; Tesar, 1980; Mueller-Warrant and Koch, 1980) and the evaluation of seeding methods for the best stand establishment (Dowling et al., 1971; Sund et al., 1966; Taylor et al., 1969).

For sod seeding to be successful, high moisture is desirable at or soon after seeding (Decker et al., 1976; Holland, 1980; Tesar, 1980), consequently seedings are most likely to be successful if made at times of the year when rainfall is plentiful. Taylor and co-workers (1969) found that sod seedings made in early spring were the most successful, later summer ones were intermediate, and those made in mid-summer were poorest. The amount and distribution of precipitation following seeding was judged by these researchers to affect germination and stand establishment more than most other factors. Early spring seedings have been shown to be the most successful and are recommended for maximum stand establishment (Tesar, 1980; Holland and Tesar, 1981).

It has been a long-standing practice of farmers to broadcast clover seeds on snow or frozen ground in late winter or early spring into fall established winter wheat. Roberts (1910) maintained clovers in a cool-season grass pasture from 1878 to 1903 by sowing early in the spring every second year, up to 2 kg ha^{-1} of mixed clover seed. Evaluation of dates and methods of seeding alfalfa and red clover in wheat were begun in Ohio in 1928 by Willard (1934) and co-workers. These researchers stated that, "Alfalfa appeared not to be as sure as red clover to make a stand if broadcast in late February or early March because the seedlings were sometimes killed by later hard freezes." Similar observations have been made in Michigan, on early-spring sod seedings of alfalfa that were considerably poorer than later seedings (Holland and Tesar, 1980).

Many studies have been conducted on freezing susceptibility and winter hardiness of field crops. Only a few researchers, however, have studied the ability of forage legume seedlings to withstand freezing temperatures. Results obtained by various investigators differ somewhat as to when seedlings are the most sensitive to freezing temperatures. White and Horner (1943) obtained 100% susceptibility to freezing injury from unemerged winter-sown alfalfa, while Peltier and Tysdal (1932) concluded that five-day-old alfalfa seedlings are more resistant to freezing than ten-day-old seedlings.

Arakeri and Schmid (1949) found no injury to unemerged seedlings but they noted a sharp decline in resistance to freezing, from emergence to the three-to-four leaf stage, after which resistance gradually increased. There seems to be a greater consensus that cold hardiness of various legumes is minimal when they are forming the first trifoliate leaf (Steinbauer, 1926) and subsequently increases with age up to 60 days (Peltier and Tysdal, 1926).

Unquestionably, because of favorable conditions of adequate moisture and increasingly warmer temperatures, spring is the ideal time to make seedings. Encouragement and advice have traditionally been given to farmers to broadcast legume seeds before the ground thaws, so early freezing and thawing will promote seed coverage. With these early seedings, it is not known how many seeds germinate and are then killed by subsequent freezing periods. The objectives of this study were: (1) to evaluate, under field conditions, if early-spring freezing temperatures are injurious to forage legume seedlings during establishment; and (2) to determine under controlled growth-chamber conditions which freezing temperatures kill forage legume seedlings during establishment.

MATERIALS AND METHODS

Section I—Field Studies

Five forage sod-seeding evaluations were conducted at three locations of diverse early-spring temperatures. The three field locations provided a range of early spring temperatures ideally suited to testing freezing injury of forage legume seedlings (Table 1). Location 1 was in an area of considerably shorter growing season than either locations 2 or 3. Annual average temperatures of these locations are indicative of the range of earliness of growth in the spring. Growth at location 3 generally preceded that at location 2 by one to two weeks and that at location 1 by three to four weeks.

Experiment 1. This study was conducted at the Lake City (LC) Experiment Station (location 1) at Lake City, Michigan, the most northerly site (44°18′N 85°12′W). The soil was an Iosco sandy loam (sandy over loamy, mixed, frigid Alfic Haplaquods) of pH 6.2. Plots were 1.8 x 7.6 m and all treatments were replicated three times in a randomized, complete block design. Alfalfa *(Medicago sativa L.)* was broadcast into the sod at 13.5 kg ha^{-1} on three different dates in 1981—15 Mar., 15 Apr., and 15 May—and drilled into the sod on 15 Apr., and 15 May. Control plots were band seeded into a plowed and tilled surface on 15 Apr. Band seeding on a prepared seedbed is considered the best method of establishing a legume stand (Tesar et al., 1954; Tesar and Jackobs, 1972) and was utilized as a check for comparing other methods of efficacy in stand establishment and production. In this and the other field experiments, actual seeding dates may have varied by two to four days but are reported as indicated for clarity of comparisons. All seedings were made by the same commercial grain-fertilizer drill with a small-seeded legume box adapted to provide precision seed setting to completely standardize seeding rates. The disk openers and coulters of the drill were retracted manually during the broadcast seeding. In the fall prior to establishing the study, *N-(Phosponomethyl)glycine* (glyphosate) was used to suppress the grasses. No fertilizer was added at seeding but recommended levels were applied annually. Stand density was determined on 19 July in four, directed 35-cm-quadrat counts from each plot. Before each harvest percent forage species in each plot was estimated visually and used to calculate the legume portion of the total forage yield. Yields were obtained from an area of 0.9 x 6.7 m with a self-propelled, direct-chop harvester. A 1-kg forage sample from representative plots was dried with forced air at 65 C for 48 hours and used for dry matter determinations. Yields are expressed in t ha^{-1} of the legume portion of the total yield.

Experiments 2 and 3. Both studies were conducted on the Crop Science Research Farm at East Lansing (EL), Michigan, (location 2) which was the most central site (42°42´N 84°28´W). Alfalfa at 13.5 and birdsfoot trefoil *(Lotus corniculatus L.)* at 7.0 kg ha^{-1} were sod seeded into a Hillsdale sandy loam (coarse-loamy, mixed, mesic, Typic Hapludalf) soil of pH 5.8. The experimental design was a randomized complete block in a split-plot arrangement with four replicates for Exp. 2 and three for Exp. 3. Agricultural limestone was applied at 11.2 t ha^{-1} prior to initiating the studies and no fertilizer was added at seeding but recommended levels were applied annually. Experiment 2 was seeded in 1979 and Exp. 3 in 1980. Seedling counts were obtained in the year of seeding for Exp. 2 on 17 July and Exp. 3 on 10 July by the same procedure as described for Exp. 1. Seeding dates, methods of seeding, grass suppression, and methods of obtaining data were the same as for Exp. 1.

Experiment 4. This study was conducted at East Lansing (location 2) on a Hillsdale sandy loam of pH 5.9 adjacent to and at the same time (1980) as Exp. 3. Alfalfa was broadcast on 15 Mar. and 15 Apr. and drilled into the sod on 15 Apr. Seedling counts were obtained on 3 July by four directed samplings from each plot, with all other treatments, statistical design, and methods of obtaining data the same as for Exp. 1.

Experiment 5. This study was conducted at the Kellogg Biological Station (KBS) near Battle Creek, Michigan (location 3), the most southerly location (42°24′N 85°24′W). Alfalfa was sod seeded into a glyphosate-treated sward on a Kalamazoo sandy loam (fine-loamy over sandy, mixed, mesic, Typic Hapludalfs) soil of pH 4.9. The experimental design was a randomized complete block in a split-split plot arrangement with four replicates. Seedings were made as follows: broadcast on 15 Mar., drilled on 15 Apr., and band seeded on a prepared seedbed on 15 Apr. (check). Seedlings were counted on 10 July by the same directed sampling method used in Exp. 1. Seeding rates, fertilization, and methods of obtaining data, were the same as in the previous trials.

Section II—Greenhouse Study

A greenhouse/growth-chamber trial was used to evaluate the specific effects of precisely controlled freezing temperatures on the killing of legume seedlings. Three forage legumes—alfalfa, red clover *(Trifolium pratense L.)*, and birdsfoot trefoil—were seeded in six replicates of 100 seeds each with 600 seeds per tray, and germinated in the greenhouse at diurnal temperatures of 18/24 C. The experimental design was a randomized complete block with a split-split plot arrangement. Seedings were made with a specially designed vacuum-operated seed head that placed 100 seeds 1 cm apart in 10 parallel rows 1 cm apart. A fungicide, *Pentachloronitrobenzine* (Terra-coat L025), was applied as a soil drench in a 1:400 ratio with water immediately after seeding to control seedling damping off diseases.

All treatments were based on imposing freezing treatments on the legumes at the same morphological dicotyledonary stage which occurred at varying times after seeding as follows: alfalfa—5 days; red clover—7 days; and birdsfoot trefoil—9 days.

The trays of seedlings in the dicotyledonary stage were placed in growth chambers for hardening periods of 2, 4, or 6 days at diurnal temperatures of 2/4 C. Seedlings were counted at the end of each hardening period and transferred to a freezing chamber for five hours at -0.5 C. At the end of this period, the trays of seedlings were sprayed with a super-fine mist of water to simulate field moisture conditions on the plant surface. The temperature was then lowered to one of five predetermined levels: -2.22, -3.33, -4.44, -5.56 or -6.67 C. The six replicates of legume seedlings were subjected to these freezing temperatures for periods of 1, 2, or 4 hours. Freezing was conducted in darkness during the "night" period. After freezing, seedlings were maintained at 3 C for 12 hours and then returned to the greenhouse. Counts were made of the surviving seedlings 48 hours later. This period was found necessary because ungerminated seeds, probably "hard" seeds, germinated after freezing and confounded counts made at longer periods after freezing. All data was analyzed using the arcsin transformation and are reported as percentages.

RESULTS AND DISCUSSION

Section—I Field Studies

Stand density was averaged separately for alfalfa for Exp. 1 to 5 and birdsfoot trefoil for Exp. 2 and 3 (Table 2) since a general pattern of performance of treatments was noted. The averaged stand densities for alfalfa and birdsfoot trefoil establishment were both ranked best, as expected (Tesar et al., 954), when band seeded into a prepared seedbed (Table 2). Band seeding, however, was better or equal to drilling the seed into the sod on the same date of 14 Apr. in all the experiments but was significantly better in only one-half of the experiments. Band seeding has been shown in many trials to produce superior stands (Tesar et al., 1954; Decker et al., 1976; Tesar and Jackobs, 1972) but data in these experiments show that in some cases with favorable rainfall and soil conditions, nearly as good stands can be obtained when drilling the seed into the sod. Broadcasting the seed on 15 Apr. was ranked third in stand establishment. It was never as good in any of the five experiments as band seeding on the same date. Drilling in the sod on 15 Apr. produced better stands than broadcasting the seed on the surface on the same date in only two of four alfalfa experiments and one of the two trefoil trials.

Drilling alfalfa seed on 15 May produced, over all experiments, the fourth-best, and trefoil, the fifth-best stands. Seedings made on this later date were all much poorer than similar seedings made one month earlier on 15 Apr. Reduced soil moisture was likely the primary reason for the poorer stands obtained in these mid-May seedings. Broadcasting alfalfa and trefoil on 15 May produced the poorest stands which were significantly lower than drilled seedings made on the same date. These poorer seedings made in May indicate the importance of seed placement when moisture is limiting, and that broadcasting seed at this late date should generally not be considered because of the likelihood of poor stands.

Early broadcast seedings of alfalfa in mid-March produced the fifth-best stands from the various seeding methods on different dates. Trefoil stands seeded on 15 Mar. were fourth best. This species variation was extremely significant as freezing temperatures were suspected to have killed seedlings of alfalfa but not of trefoil. Broadcast seedings of alfalfa made on 15 Apr. produced better stands at all locations than similar seedings made on 15 Mar.

There was no difference, however, in stand establishment of trefoil when broadcast on 15 Mar. or 15 Apr. Trefoil germinates and develops much more slowly than alfalfa and, even though germination had occurred at the time of the freezing temperatures, trefoil was shown to be more resistant to freezing than alfalfa. This is substantiated by additional work conducted in the greenhouse and reported later in this study that shows trefoil is more resistant than alfalfa to freezing temperatures in the seedling stage. An examination of temperatures recorded at the experiment sites will help explain why stands of alfalfa were established more readily on one date compared to another. Broadcast seedings of alfalfa at East Lansing, location 2

(Exp. 2) in the spring of 1979 produced a better stand (64%) when broadcast on 15 Apr. than when seeded on 15 Mar. Figure 1 indicates two freezing periods (25 to 29 Mar., and 3 to 11 Apr.) when seedings made on 15 Mar. could have been killed. Temperatures dropped to -10 C in the first and to -9 C in the second period. Time and temperatures were not sufficient for germination of the alfalfa seeds before the first freezing period in late March but germination had occurred prior to the freezing temperatures on 3 to 11 Apr. Birdsfoot trefoil seedings in the same experiment (2) were not affected by these freezing temperatures because of a greater resistance to freezing injury.

Seedings made a year later (1980) at the same location (EL), (Exp. 3 and 4) produced very similar results (Table 2) to those of the 1979 seeding (Exp. 2). Alfalfa stands were 72 and 86% better in Exp. 3 and 4, respectively, from the 15 Apr. broadcast method than from those broadcast on 15 Mar. During 13 to 17 Apr. temperatures dropped to almost -6 C at location 2 (EL) (Fig. 2). This was after temperatures had been high enough to permit germination of the alfalfa seeds and killing of the young seedlings may have resulted from this period of freezing. When seeded on 15 Mar., trefoil stands in Exp. 3 were not reduced as were the alfalfa stands.

In Exp. 1 seeded at Lake City (location 1) in 1981, the alfalfa stand was 137% better when broadcast on 15 Apr. than when broadcast on 15 Mar. (Table 2). Four periods of freezing temperatures (Fig. 3) ranging from -1 to -9 C during 5 to 6, 15 to 16, 18 to 22, and 24 to 27 Apr. were likely low enough to kill alfalfa seeded on 15 Mar.

At the southern-most location (3) at the Kellogg Biological

Station (KBS), alfalfa seeded in Exp. 5 showed the same trends of the effect of freezing temperatures after various seedings dates as in each of the other trials. Broadcasting alfalfa in mid-April produced a 178% better stand than the mid-March broadcast seeding (Table 2). Trefoil stands, however, were not adversely affected when broadcast in mid-March. Temperatures (Fig. 4) indicated four periods of freezing (-1 to -4 C) after the mid-March seeding date that could have killed the alfalfa seedlings. The magnitude of freezing required to significantly reduce a stand of alfalfa was not known at the time of these trials but subsequent work reported in this chapter shows that the freezing temperatures of -1 to -4 C after seeding likely killed some of the alfalfa seedlings. The temperatures may not have killed the seedlings outright but may have had a weakening effect by the repeated freezing at the two-to three-day intervals from mid-to late April.

Similarly to averaging stand densities for the various locations because of similarities noted, yields from the year after seeding are also averaged for each legume. These yields (Table 3) showed no difference in dry matter production of alfalfa or trefoil between the broadcast mid-March and band, broadcast or drilled mid-April seedings, except in Exp. 5. This lack of yield differences was not unexpected even though stands were better from the mid-April seedings as work reported by Tesar (1978) showed that yields in the year after seeding from 32 alfalfa plants ha^{-1} (13. 9 t ha^{-1}) was almost equal to yields from 160 plants ha^{-1} (14.6 t ha^{-1}). Bolger and Meyer (1983) reported on work in North Dakota that showed no difference in yield in the year after seeding from alfalfa stands ranging from 54 to 484 plants m^{-2}. Other work has also been done demonstrating a yield plateau above certain stand density levels and a lack of significant yield increases proportional to higher stand density (Palmer and Wynn-Williams, 1976; Tysdal and Kiesselbach, 1939). Reduced competition to the quackgrass regrowth by the poorer stand of alfalfa in the March broadcast seeding (Exp. 5) may have contributed to the lower yield.

Broadcast seedings made in mid-May (Table 3) produced unsatisfactorily low yields except in Exp. 3 at East Lansing where yields were equally as good as those from all the other seeding methods. Favorable rainfall (31 mm) two days after seeding on 15 May in Exp. 3, followed by a well-distributed, above-normal precipitation over the next six weeks, helped establish a stand of 55 plants m^{-2}. This stand density has been shown by other researchers (Tesar, 1978; Bolger and Meyer, 1983) to be adequate for maximum yields. Precipitation was lower and not well distributed after May seedings in other years at each location showing that broadcast seeding in Mid-May is not a satisfactory method of stand establishment. When the seed was drilled into the sod in mid-May stands were more satisfactory, even though not as good as mid-April seedings, and produced yields almost as high as these earlier seedings.

Section II—Greenhouse Study

The greenhouse trials produced a definite ranking of the three legume species indicating differences in cold resistance dependent on the length of hardening period and, more importantly, on the freezing temperature. Differences in survival were only minor when the legumes were hardened for 2, 4, or 6 days (Tables 4, 5, 6) but some important differences were noted. One hour of freezing at the three lowest temperatures showed red clover to be as cold resistant as trefoil (Table 4). After two hours at these same temperatures, trefoil was the most cold resistant and red clover did not survive any better than alfalfa (Table 5). The distinct ranking of cold resistance between the legumes was clearly shown after four hours of freezing at -6.67 C (Table 6): trefoil > red clover > alfalfa. Two (Table 4) and four days (Table 5) of hardening produced similar survival rates with slightly higher legume survival after six days (Table 6) of hardening. The data in Tables 4, 5, and 6 are averaged (Fig. 5), therefore, to show the effects of various lengths of freezing—1, 2, or 4 hours—at temperatures ranging from -2.22 to -6.67 C. This comparison is considered justifiable since it is likely, under actual field conditions, that the greatest variance in seedling mortality would likely be related more to this combination of duration and degree of freezing, rather than to the length of hardening.

Differences in legume resistance to freezing injury, averaged over the hardening periods (Fig. 5) show that at 1, 2, and 4 hours of sub-zero temperatures, significant differences among the legumes were first produced at -5.56, -4.44, and -3.33 C, respectively. At all temperatures lower than this, survival was consistent: trefoil > red clover > alfalfa. It is not known why red clover did not withstand -5.56 C for two hours any better than alfalfa. Since all other data with higher and lower freezing temperatures indicated red clover seedlings were more resistant to freezing than alfalfa, it is suggested that these data at -5.56 C, for some unknown reason, do not accurately represent differences at this level.

When frozen for four hours at -2.22 C (Fig. 5), red clover and trefoil were more cold resistant than alfalfa. This indicated that alfalfa was also more adversely affected by the length of the freezing period than either red clover or trefoil. Only 32% of the alfalfa seedlings survived -3.33 C for four hours which was less than one-half the survival rate of red clover (73%) or trefoil (85%).

The averaged freezing period (1, 2, and 4 hours) data in Fig. 6 show that the three legumes had the following "cardinal" freezing temperatures at which 50% of the seedlings in the dicotyledonary stage were killed (LT_{50}): alfalfa -4.44 C (24 F); red clover -5.39 C (22.3 F); and trefoil -6.67 C (20 F). These data (Fig. 6) showing the LT_{50} for each legume corroborate the field data presented in Section I of this chapter where mid-March seedings of alfalfa were reduced by freezing temperatures but trefoil stands were not.

Alfalfa seedings made in Michigan in mid-March will be injured and the stand depleted by likely freezing temperatures of -4.44 C, (24 F) that are common during this time, but seedings of red clover, and especially trefoil, are less likely to be injured. These two legumes which are more resistant to freezing than alfalfa in the seedling stage, should be established just as successfully if seeded in mid-March or mid-April. Broadcast seeding of alfalfa, then, would likely be more successful if made in early to mid-April to benefit from spring rains with a lower probability of freezing temperatures.

These data also substantiate why early-spring (Feb. to Mar.) broadcast seedings of alfalfa in winter wheat are generally less sucessful than similar seedings of red clover because of the freezing temperatures encountered at this time.

SUMMARY AND CONCLUSIONS

Five field trials were conducted at three locations of diverse early-spring temperatures to evaluate the resistance to freezing of alfalfa and birdsfoot trefoil in the dicotyledonary stage. A greenhouse/growth-chamber study was used to evaluate, under controlled conditions, the precise temperatures at which seedlings of these two forage legumes and red clover were killed.

Alfalfa stands were consistently poorer but trefoil seedings were equal when broadcast seeded in mid-march than in mid-April. Band seeding into a prepared seedbed produced the best stands overall, of alfalfa and trefoil. Seedings drilled in the sod in mid-April, however, produced stands equal to band seedings in one-half the field experiments, showing this to be a satisfactory seeding option. Drilled seedings in mid-May were satisfactory but broadcast seedings made on 15 May were unsatisfactory in all but one experiment.

Yields, obtained in the year after seeding, generally, did not reflect the differences in stand density unless the stands were very poor. Yields of alfalfa were best when seeded in mid-April, poorer when broadcast in mid-March or drilled in mid-May and poorest when broadcast in mid-May. Trefoil produced yields in a similar pattern to alfalfa, but mid-May drilled seedings also produced as good yields as mid-April seedings. It was concluded from these field and controlled temperature studies that:

1. Early-spring freezing temperatures in the field killed many alfalfa, but not trefoil, seedlings.

2. Alfalfa was least resistant to freezing temperatures, red clover was intermediate, and trefoil the most resistant.

3. After freezing for an average of 2.3 hours, the LT_{50} for alfalfa was -4.44, red clover -5.39, and trefoil -6.67 C.

4. Sod seedings of alfalfa are best made in Michigan in early to mid-April to reduce the likelihood of freezing injury to the seedlings. Red clover is more cold resistant and can be seeded two to three weeks earlier than alfalfa. Trefoil can be seeded equally as well in mid-March or mid-April.

5. Satisfactory stands and yields of birdsfoot trefoil can be obtained on herbicide-suppressed sods by the economical broadcasting of seeds earlier in the spring than is possible to drill the seed into the sods.

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Table 1. Climatological data from the National Oceanic and Atmospheric Administration for the three experimental locations in Michigan.

Location	Frost-free days	Annual temperatures C		
		Max.	Min.	Average
1-Lake City	97	31.1	-32.2	5.7
2-East Lansing	151	33.3	-24.4	7.6
3-Kellogg	159	33.3	-25.5	9.3

Table 2. Stand density three months after seeding forage legumes at three locations on three different dates during 1979, 1980, or 1981.†

			Location								
			1-LC	2-EL			3-KBS		2-EL		
Seeding			Experiment								
Date	Method	Surface	1	2	3	4	5	Average	2	3	Average
			Seedlings m^{-2}								
			Alfalfa						Trefoil		
15 Mar.	broadcast	sod	43	79	67	69	46	61 (5)‡	65	57	61 (4)
15 Apr.	broadcast	sod	102	129	115	128	128	120 (3)	65	71	68 (3)
15 Apr.	drilled	sod	196	161	115	146	153	154 (2)	80	94	87 (2)
15 Apr.	band	tilled	180	163	182	-	254	195 (1)	97	157	127 (1)
15 May	broadcast	sod	1	10	55	-	-	22 (6)	3	-	3 (6)
15 May	drilled	sod	78	66	78	-	-	74 (4)	39	55	47 (5)
	$LSD_{0.05}$		25	30	19	20	32		30	19	

†Experiment 2 seeded in 1979; 3 and 4 in 1980; 1 and 5 in 1981.

‡Ranking of best(1) to poorest(6).

Table 3. Yield of forage legumes from three harvests in the year after seeding.†

Seeding			Location								
			1-LC	2-EL			3-KBS		2-EL		
			Experiment								
Date	Method	Surface	1	2	3	4	5	Average	2	3	Average
			t ha^{-1}								
			Alfalfa						Trefoil		
15 Mar.	broadcast	sod	5.4	7.1	12.0	13.3	9.5	9.5 (4)‡	6.2	3.9	5.1 (5)
15 Apr.	broadcast	sod	6.3	8.0	12.0	12.9	10.6	10.0 (3)	6.2	4.3	5.3 (4)
15 Apr.	drilled	sod	7.2	11.8	12.2	13.6	10.7	11.1 (1)	8.6	8.9	8.8 (2)
15 Apr.	band	tilled	7.7	11.5	11.8	-	11.6	10.7 (2)	9.0	9.0	9.0 (1)
15 May	broadcast	sod	0.1	1.8	11.9	-	-	4.6 (6)	0.2	-	0.2 (6)
15 May	drilled	sod	5.5	8.7	12.1	-	-	8.8 (5)	5.3	6.5	5.9 (3)
	$LSD_{0.05}$		2.3	1.3	NS	NS	0.5		1.3	2.9	

†Experiment 2 harvested in 1980; 3 and 4 in 1981, 1 and 5 in 1982.

‡Ranking of best(1) to poorest(6).

Table 4. Percent survival of three forage legumes after two days of hardening and 1, 2, or 4 hours of freezing.

	Temperature C				
	-2.22	-3.33	-4.44	-5.56	-6.67
	One hour freezing				
Alfalfa	100	79 *a*	73 *a*	60 *a*	61 *a*
Red clover	100	94 *b*	97 *b*	74 *a*	72 *a*
Trefoil	100	96 *b*	95 *b*	87 *b*	84 *b*
	Two hours freezing				
Alfalfa	98 *a*	48 *a*	42 *a*	18 *a*	16 *a*
Red clover	99 *a*	90 *b*	56 *b*	27 *ab*	28 *b*
Trefoil	100 *a*	91 *b*	67 *b*	35 *b*	46 *b*
	Four hours freezing				
Alfalfa	91 *a*	26 *a*	18 *a*	3 *a*	4 *a*
Red clover	98 *b*	72 *b*	28 *ab*	14 *b*	12 *b*
Trefoil	100 *b*	80 *b*	37 *b*	18 *b*	18 *b*

Means followed by the same letter within columns and freezing periods do not differ at the 5% level of probability according to Duncan's multiple range test.

Table 5. Percent survival of three forage legumes after four days of hardening and 1, 2, or 4 hours of freezing.

	Temperature C				
	-2.22	-3.33	-4.44	-5.56	-.6.67
	One hour freezing				
Alfalfa	100	87 *a*	77 *a*	61 *a*	60 *a*
Red clover	100	99 *b*	95 *b*	82 *b*	79 *b*
Trefoil	100	100 *b*	98 *b*	90 *b*	86 *b*
	Two hours freezing				
Alfalfa	100 *a*	69 *a*	43 *a*	23 *a*	17 *a*
Red clover	98 *a*	93 *b*	68 *b*	26 *a*	30 *b*
Trefoil	100 *a*	96 *b*	70 *b*	44 *b*	39 *b*
	Four hours freezing				
Alfalfa	93 *a*	33 *a*	22 *a*	8 *a*	9 *a*
Red clover	100 *b*	71 *b*	29 *ab*	12 *ab*	13 *ab*
Trefoil	100 *b*	81 *b*	35 *b*	21 *b*	17 *b*

Means followed by the same letter within columns and freezing periods do not differ at the 5% level of probability according to Duncan's multiple range test.

Table 6. Percent survival of three forage legumes after six days of hardening and 1, 2, or 4 hours of freezing.

	Temperature C				
	-2.22	-3.33	-4.44	-5.56	-6.67
	One hour freezing				
Alfalfa	100	100	80 *a*	77 *a*	74 *a*
Red clover	100	100	97 *b*	90 *b*	87 *b*
Trefoil	100	100	98 *b*	92 *b*	91 *b*
	Two hours freezing				
Alfalfa	100	96 *a*	69 *a*	34 *a*	27 *a*
Red clover	100	93 *a*	74 *a*	36 *a*	39 *ab*
Trefoil	100	98 *a*	91 *b*	63 *b*	43 *b*
	Four hours freezing				
Alfalfa	99 *a*	38 *a*	25 *a*	10 *a*	9 *a*
Red clover	100 *a*	77 *b*	35 *a*	20 *a*	18 *b*
Trefoil	100 *a*	95 *c*	85 *b*	42 *b*	29 *c*

Means followed by the same letter within columns and freezing periods do not differ at the 5% level of probability according to Duncan's multiple range test.

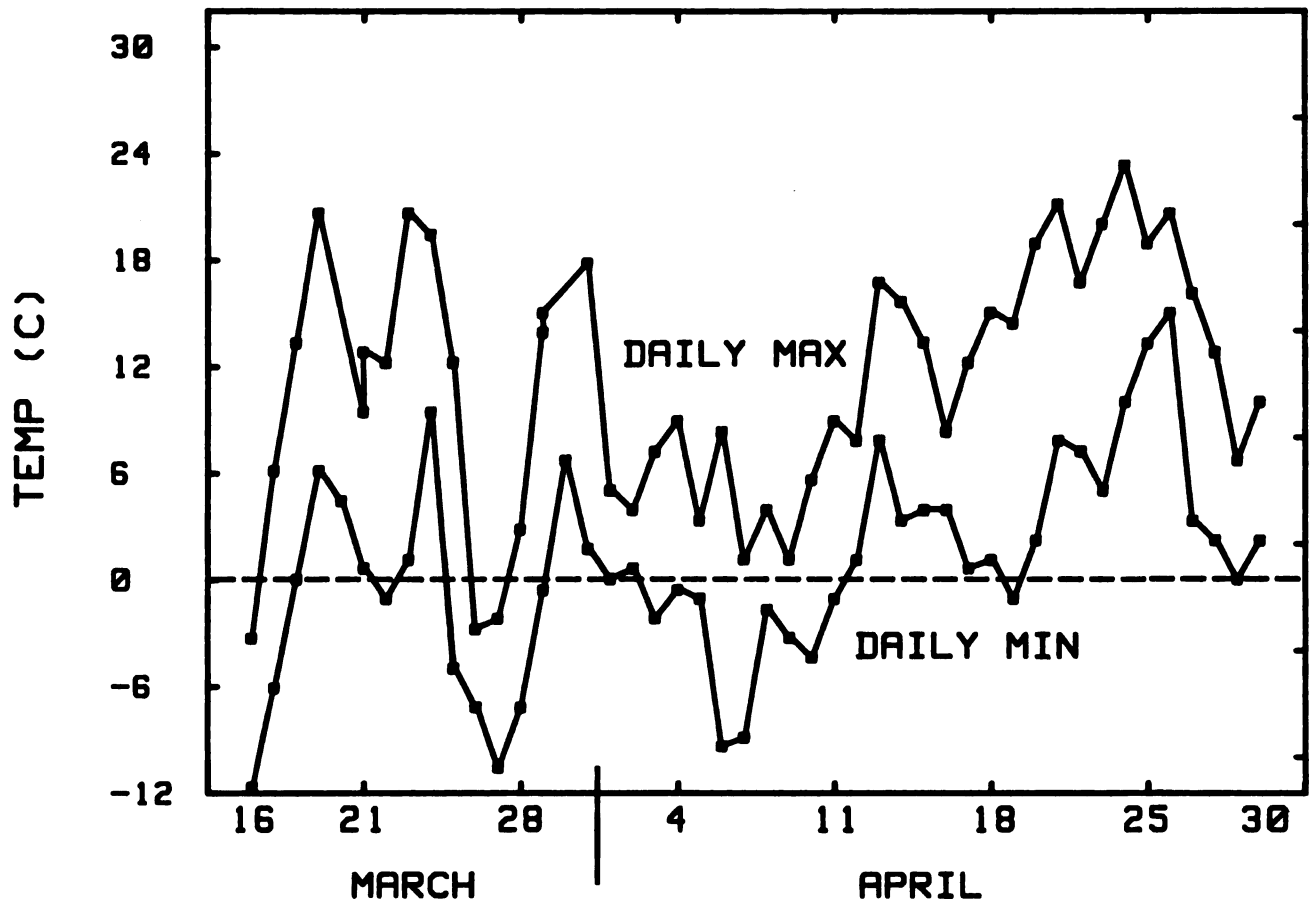


Fig. 1. Selected early spring daily maximum and minimum temperatures for 1979 at Location 2 (East Lansing).

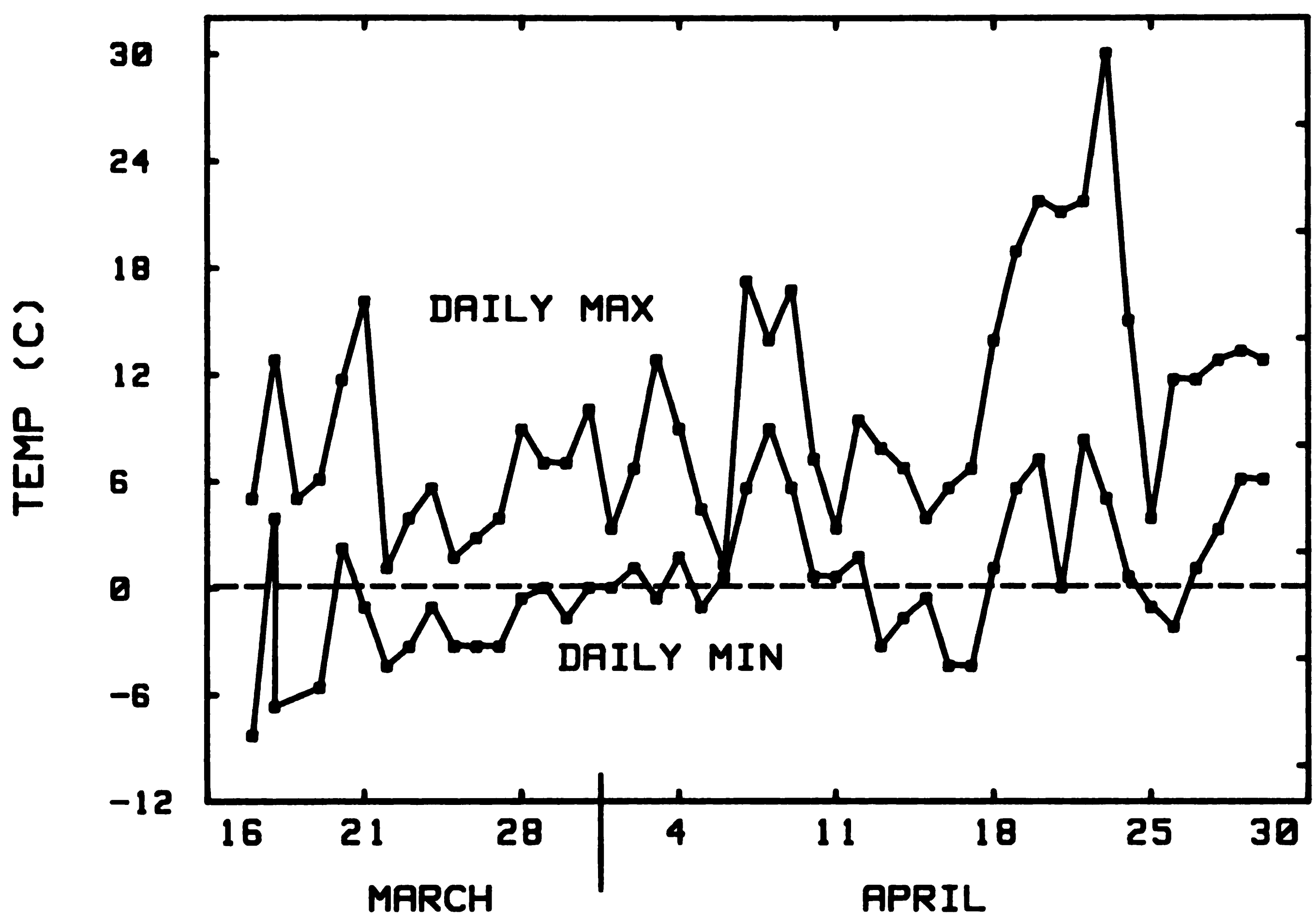


Fig. 2. Selected early spring daily maximum and minimum temperatures for 1980 at Location 2 (East Lansing).

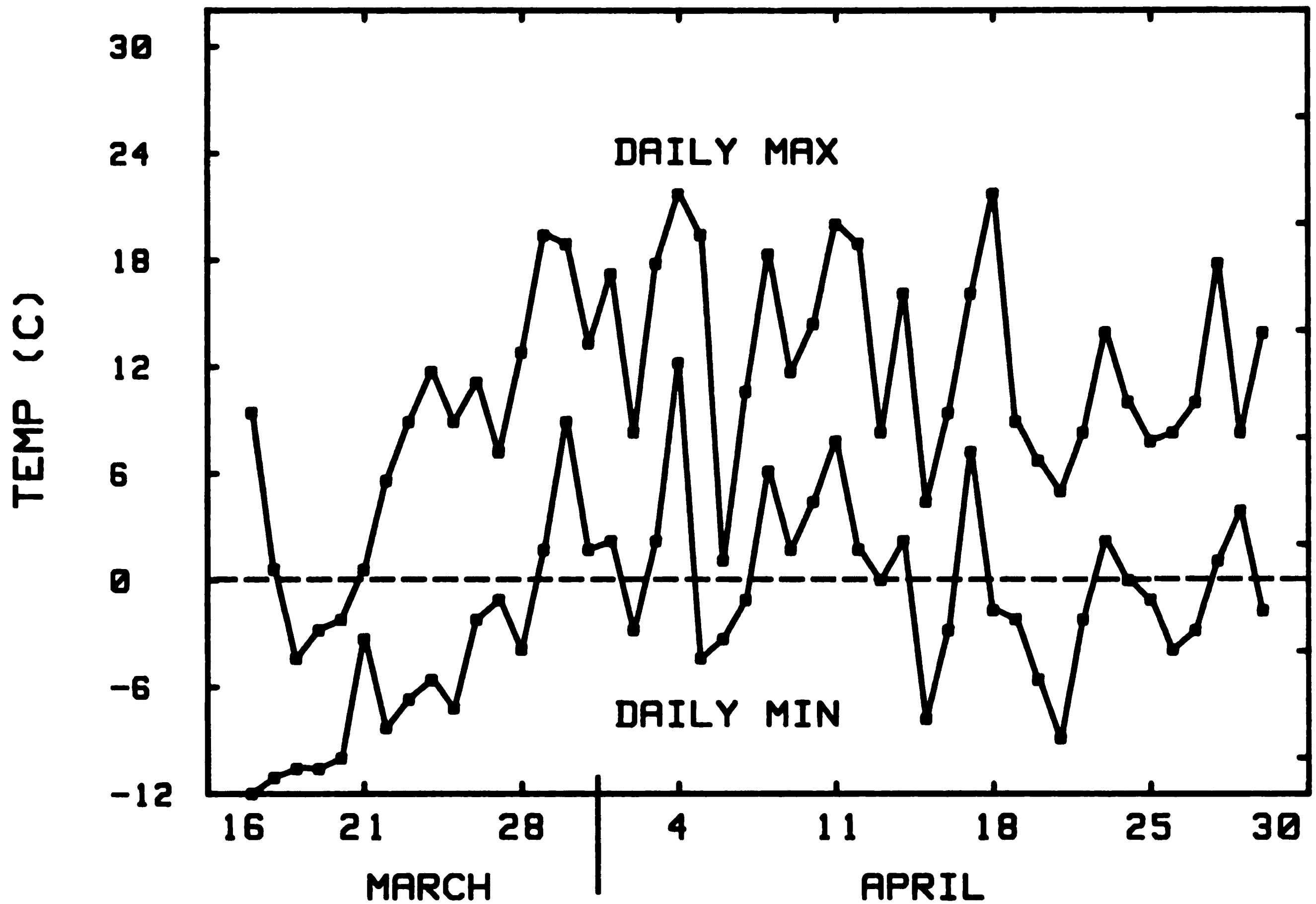


Fig. 3. Selected early spring daily maximum and minimum temperatures for 1981 at Location 1 (Lake City).

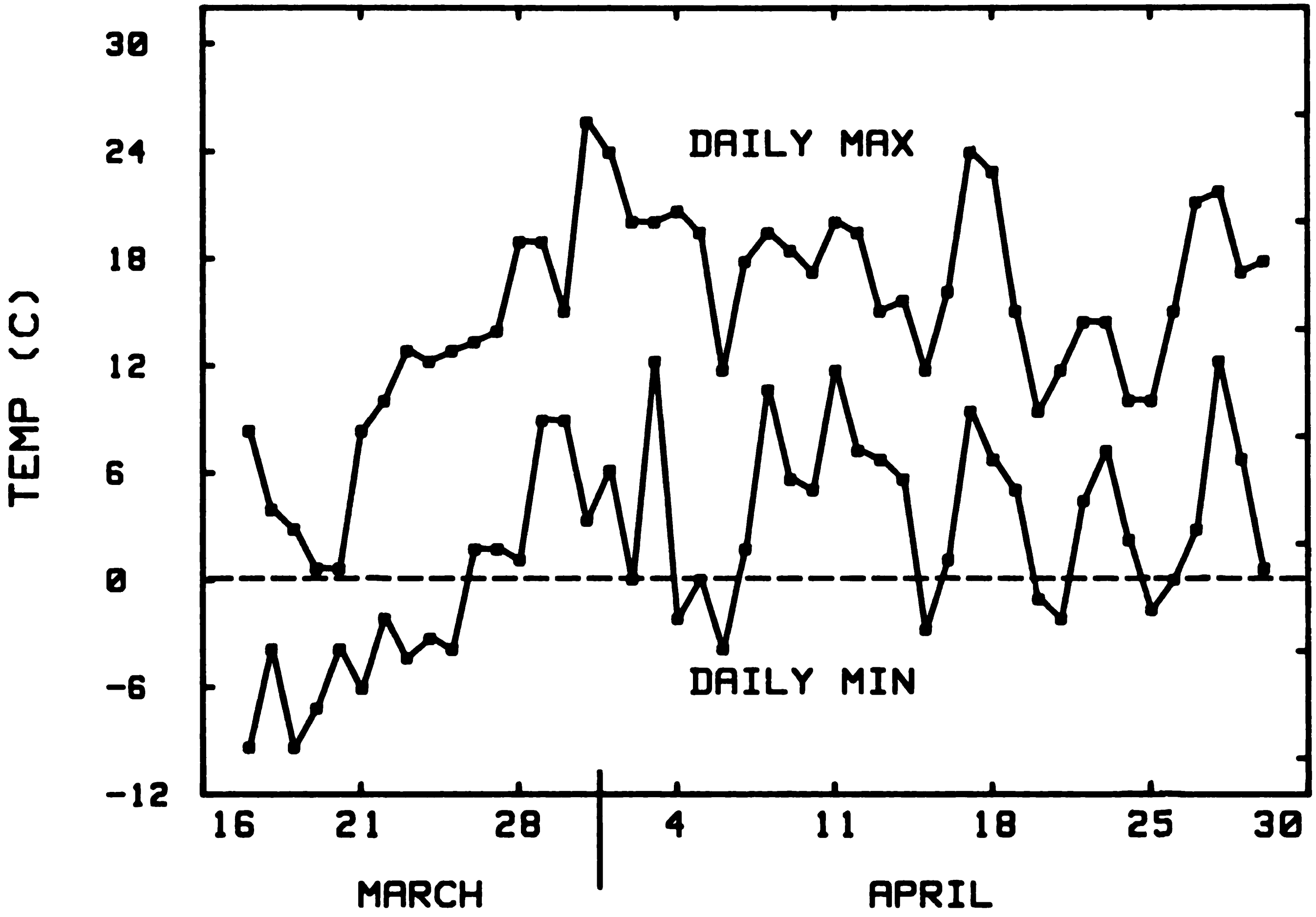
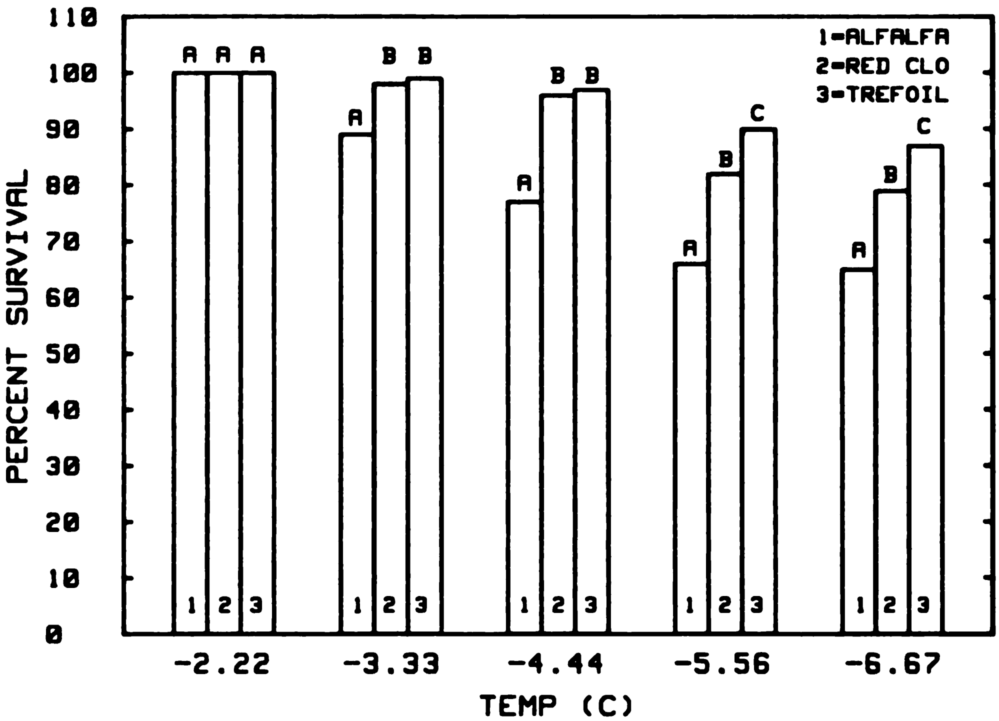
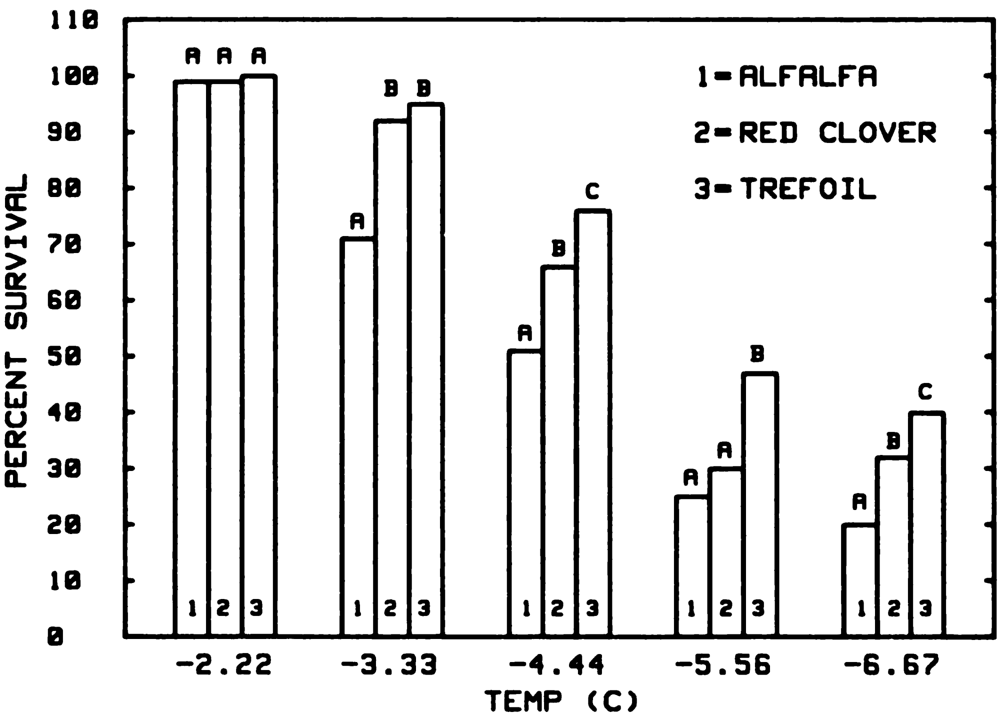


Fig. 4. Selected early spring daily maximum and minimum temperatures for 1981 at Location 3 (Kellogg).



110
100
90
80
70
60
50
40
30
20
10
0
PERCENT SURVIVAL
1=ALFALFA
2=RED CLO
3=TREFOIL
A A A
A B B
A B B
A B C
A B C
1 2 3
-2.22
-3.33
-4.44
-5.56
-6.67
TEMP (C)



110
100
90
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70
60
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40
30
20
10
0
PERCENT SURVIVAL
1=ALFALFA
2=RED CLOVER
3=TREFOIL
A A A
A B B
A B C
A A B
A B C
1 2 3
-2.22
-3.33
-4.44
-5.56
-6.67
TEMP (C)

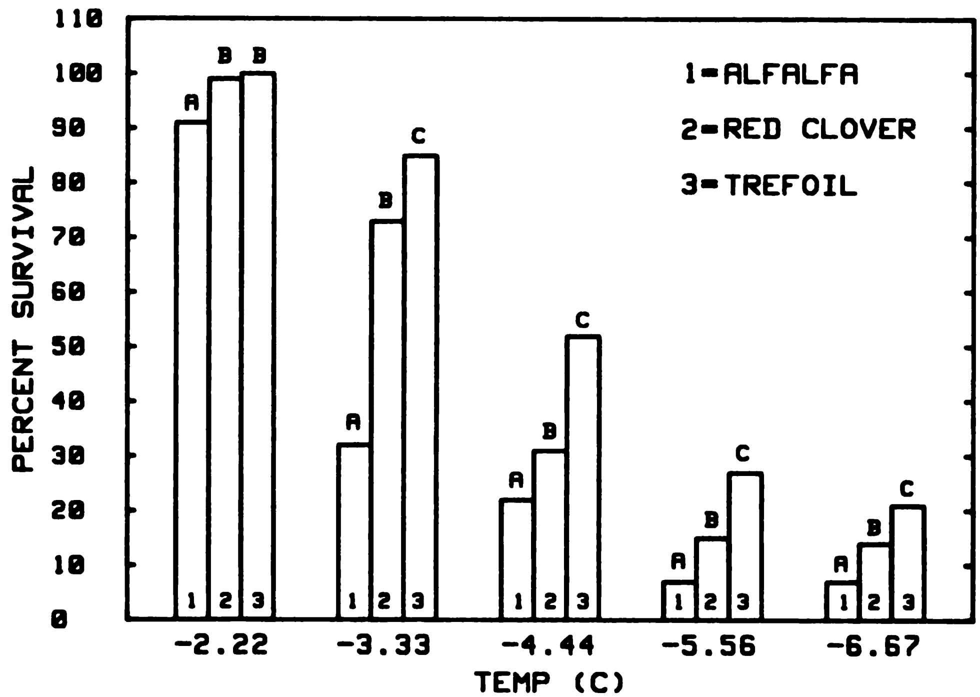

Fig. 5. Percent survival of three forage legumes after being frozen for one (opposite top), two (opposite lower), and four hours (above) and averaged over the three hardening periods of two, four and six days.

Dis-similar letters at the top of columns within each temperature indicate differences between species at the 5% level of probability according to Duncan's multiple range test.

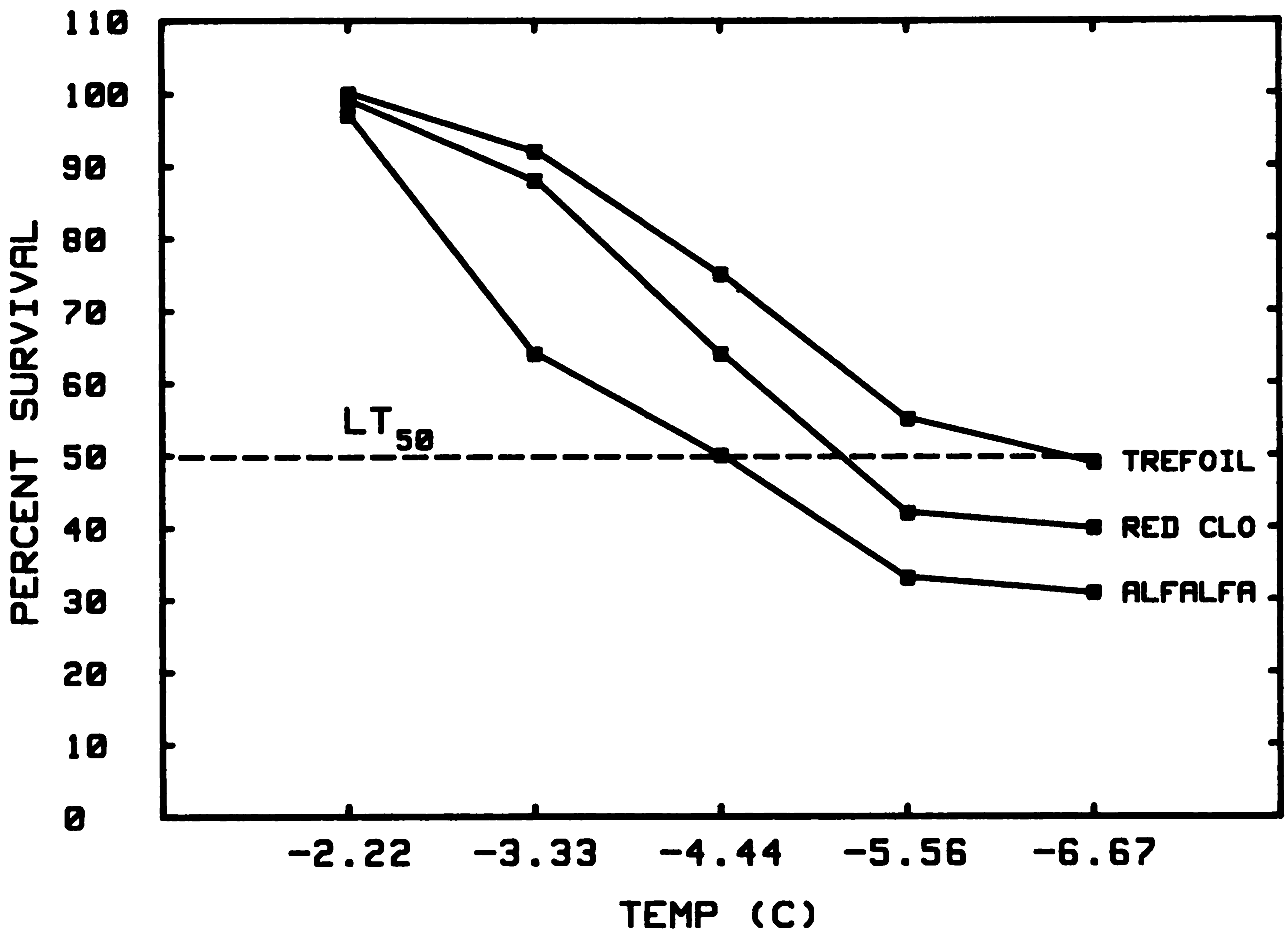

Fig. 6. Percent survival of three forage legumes averaged over three freezing times (1, 2, and 4 hours) and three hardening periods (2, 4, and 6 days).

CHAPTER 3

SIMULATED GRAZING COMPARED TO HERBICIDE SUPPRESSION OF GRASS COMPETITION WHEN SOD SEEDING FORAGE LEGUMES

ABSTRACT

Grass pastures are more productive when the sward contains a nitrogen fixing legume. Complete tillage and reseeding, or sod seeding and suppression of existing foliage with herbicides, have been two very successful methods for improving pastures by introducing legumes. Both methods require specialized equipment and costly inputs such as fossil energy and chemical herbicides. Many of the grassland areas in need of improvement are operated by marginal producers and livestock farmers who do not own the necessary equipment or cannot afford the higher costs involved in chemical renovation.

This study was designed to (1) compare mechanical defoliation, simulating grazing, of grass sods with an accepted herbicide to suppress competition to sod seeded forage legumes and; (2) determine stand establishment and yields from seed broadcast on the surface in early spring or drilled into the sod four weeks later.

Red clover *(Trifolium pratense L.)* and birdsfoot trefoil *(Lotus corniculatus L.)* seed was broadcast on 26 Mar. and drilled on

21 Apr. into bromegrass *(Bromus inermis L.)*, reed canarygrass *(Phalaris arundinacea L.)*, orchardgrass *(Dactylis glomerata L.)*, and quackgrass *(Agropyron repens L.)* sods. Competition from these grasses defoliated 0, 2, or 4 times during the seeding year was compared to suppression by the herbicide *3,5-dichloro-N-(1,1-dimethyl-2-propynyl)benzamide* (pronamide) applied in the fall prior to seeding. Defoliation dates were 15 May and 15 July for the two- and four-cut series, with additional cuts made on 5 June and 26 Aug. for the four-cut treatment. Seedling counts obtained 3 and 15 months after seeding and legume yields from the first and second years after seeding were used to evaluate treatments.

Suppression of the grasses by cutting or with a herbicide was essential for legume establishment and good yields. Four cuts of the sown grasses improved red clover and trefoil establishment more consistently than herbicide suppression. Herbicide control of vigorous quackgrass was more successful than the defoliation treatments. Less vigorous quackgrass was suppressed equally well by 4 cuts or the herbicide.

Early (26 Mar.) broadcast and later (21 Apr.) drilled seedings of trefoil were equally good. Red clover stands were best when drilled into quackgrass sods but equally good from both seeding methods in sown grasses. Year-after-seeding stand density indicated no long-term advantage of drilling seed in the sod, compared to broadcasting it on the surface.

Additional index words: Pasture improvement, grass suppression, defoliation, frost seeding, *Trifolium pratense L.*, *Lotus corniculatus L.*

INTRODUCTION

Introducing and maintaining legumes in grass swards has been tried in a variety of ways, from broadcasting seeds on the surface in the winter (Roberts, 1910; Dowling et al., 1971), herbicide application to the sod to reduce competition (Sprague, 1952; Triplett et al., 1975; Van Keuren and Triplett, 1970; Tesar, 1976); strip tillage (Taylor et al., 1969; Decker et al., 1964); improved fertilization (Baker, 1980; Decker et al., 1969); and the use of specialized seeding equipment (Ackley, 1975; Harris, 1974; Olsen et al., 1981). Partial tillage with disk harrows and field cultivators has been utilized on sods to obtain a suitable seedbed (Smith et al., 1973) and lime coating of the introduced seeds has been used successfully in drier environments (Dowling et al., 1971; White, 1970). The availability of moisture to the introduced seedlings is perhaps the most crucial factor in the success of all sod seedings (Suckling, 1976; Dowling et al., 1971; Taylor et al., 1969). Almost as important is the reduction of competition from the existing sward to the inter-seeded species. This has been carried out in many different ways such as close grazing, burning, disking, field cultivating, and the use of herbicides (Graber, 1927; Sprague, 1960; Cullen, 1966). Moisture is not a controlled input but seedings can be made at a time when it is most abundant. Competition to introduced seedlings is controllable but is also costly in time, equipment and/or chemicals.

Grasslands most often involve herbivore animals that could be utilized in the reduction of plant inter-species competition by grazing the sod-seeded areas.

As early as 1878, Roberts (1910) utilized dairy cattle to graze a grass pasture inter-seeded with a mixture of red and alsike clover seeds. He observed that one mechanical mowing was necessary to remove rank growth of the grasses in late June after which a good clover stand was produced. After the clovers were well established the pastured area carried three times as many cattle as the average pastures of New York state. Graber (1927) suggested that poor pasture production was often the result of overgrazing. He maintained that deferred grazing was necessary to allow regrowth of plants to replenish food reserves in storage organs if the pasture vigor and productivity were to be maintained. Severe overgrazing without added fertilizer resulted in heavy weed infestation in bluegrass pastures (Fuelleman and Graber, 1938). They listed 47 weed species in the pasture and with pasture renovation and improved grazing management they markedly reduced the weed population. Burcalow et al. (1940) showed that without judicious management, the duration and value of pasture improvement was greatly reduced. Moderate grazing of renovated pastures resulted in better legume persistence and fewer weeds than excessively grazed renovated pastures. While acknowledging grazing as a common practice in aiding renovation of pastures, Ahlgren et al. (1940) successfully sod-seeded pastures with sweet and red clover without any summer defoliation in the year of seeding. Love (1944) compared grazing by sheep and mechanical mowing of species to reduce competition in stand establishment and concluded that the timing and management of the grazing produced a vigorous stand of perennials. Mowing was not managed on a similar schedule to the grazing and resulted in poorer stands.

In areas of steep hillsides, mowing is not possible and grazing of garss competition with sheep or cattle is the only practical method of reducing competition to introduced legumes. On New Zealand hill lands, close, frequent grazing generally proved superior to infrequent grazing for grass germination and survival, but it seldom aided clover germination although clover survival was improved (Cullen, 1970). Robinson and Cross (1960) found grazing of permanent-pastured hill lands beneficial during early establishment with sod seeding. Suckling (1976) found no difference in the establishment of red clover, subterranean clover, and lotus major, subjected after seeding to three grazing regimes of continuous grazing, and variable periods of rotational grazings. He did find, however, that white and red clover were established better on sods grazed before seeding to 1 to 2 cm than pasture 5 to 10 cm long.

Close grazing or clipping is essential for successful legume stand establishment if other suppression methods are not used. Barnhart and Wedin (1981) found that it was necessary to clip a bromegrass sward every two to three weeks when sod seeding trefoil as light penetration of the canopy was reduced by over 50% within 20 days following clipping. Decker and Dudly (1976) concluded that complete suppression of a grass sward with herbicides was neither necessary or desirable as severe weed invasions often occurred. Inter-seeding forage legumes into a sod and reducing grass competition with grazing or clipping would prevent weed infestations and maintain greater productivity than that obtained with a complete herbicide kill. Taylor and Allinson (1983) established alfalfa and trefoil in various grass sods by reducing competition with several clippings in the year of seeding. Livestock producers could, with judicious management, continue to graze sod-seeded pastures without interruption to productivity while at the same time reducing competition to introduced legumes. Costly inputs and production interruptions are considered major drawbacks in producer acceptance of pasture improvement by sod seeding.

This study was designed to (1) determine how successful renovation of low-producing sown grass and quackgrass pastures would be by broadcasting seed compared to using specialized, expensive machinery in sod seeding; and (2) compare several levels of mechanically simulated grazing with a recommended herbicide in reducing grass competition to introduced seedlings when sod seeding forage legumes in sown grasses or quackgrass sods.

MATERIALS AND METHODS

Four field experiments were conducted on two different soil types in the same general area at the Lake City Experiment Station, Michigan, in three different sown grass swards and two predominately quackgrass *(Agropyron repens L.)* sods. Two legumes, 'Arlington' red clover *(Trifolium pratense L.)* and 'Viking' birdsfoot trefoil *(Lotus corniculatus L.)* were sod seeded on two dates into grass swards suppressed before seeding by a herbicide, or by mowing at various frequencies after seeding to reduce grass competition. The use of herbicides is a well established and approved method of reducing grass competition when sod seeding (Sprague, 1960; Triplett et al., 1975; Decker and Dudly, 1976; Tesar, 1980).

The two methods of sod seeding were:

1. Drilling seed into the sod at the earliest practicable date on 21 Apr. with a commercial grain-fertilizer drill with a small-seeded legume box adapted to provide precision seed setting.

2. Broadcasting seed on the sod surface on 26 Mar. to maximize the benefit of early spring thaws and rains in the germination of the uncovered seeds. The same commercial drill was used for both seeding methods so as to completely standardize the seeding rates. The disk openers and coulters of the drill were retracted manually during the broadcast operation.

The four methods of grass suppression were:

1. No cutting in the year of seeding.

2. Two cuttings, to simulate rotational grazing, made on 15 May and 15 July after seeding.

3. Four cuttings, to simulate more frequent rotational grazing, made on 15 May, 5 June, 15 July, and 26 Aug.

4. Herbicide suppression of the grasses with *3,5-dichloro-N-(1,1-dimethyl-2-propynyl)benzamide* (pronamide) which was fall applied at 1.7 kg ha^{-1} in 1979 to selected plots within each grass species. This herbicide was utilized as a check treatment and suppresses grasses, except orchardgrass, adequately for legume establishment when sod seeding (Holland, 1980; Triplett et al., 1977).

Experimental design for the four experiments was a split-split block replicated four times for Exp. 1 and 2 and three times for Exp. 3 and 4. Recommended rates of fertilizer were applied on the surface at seeding and during each subsequent year of the trials. Other differences among the experiments were as follows:

Experiment 1. This study was located on a Kent silt loam (Fine, illitic Typic Eutroboralfs) of pH 5.3 with well established bromegrass (BG) *(Bromus inermis L.)*, reed canarygrass (RCG) *(Phalaris arundinacea L.)*, and orchardgrass (OG) *(Dactylis glomerata L.)* in adjacent blocks. Red clover was seeded into these grasses at 13.5 kg ha^{-1}.

Experiment 2. Birdsfoot trefoil was seeded at 6.7 kg ha^{-1} into reed canarygrass and orchardgrass sods adjacent to Exp. 1.

Experiment 3. Red clover and birdsfoot trefoil were seeded into an 80% quackgrass sod in an area adjacent to Exp. 1 and 2 on a soil of pH 6.3.

Experiment 4. This trial was established on an Iosco loamy sand (sandy over loamy, mixed, frigid Alfic Haplaquods) of pH 5.7. Red clover and birdsfoot trefoil were seeded into the 90% quackgrass sod as in Exp. 3, except that flooding prevented the broadcast seedings of trefoil from being made until the later date of the seedings made by drilling in the sod.

Data were obtained from all the experiments in an identical manner on the same dates. Stand density was determined on 15 July by counting legume seedlings in four directed, 35-cm quadrat samplings from each plot. A permanent 15-cm stake placed in the soil at ground level in the northeast corner of each quadrat sampled enabled precise counts to be made on plant survival by counting the same area 12 months later.

Two harvests were made in each of the first and second years after seeding. Prior to each harvest the percent legume in each plot was estimated visually and used to calculate pure legume yield. Harvests were made from a 0.9 x 8.2 m area with a self-propelled, direct-chop harvester. A 1-kg forage sample from selected plots was dried with forced air at 65 C for 48 hours and used to determine dry matter. Yield data are reported in dry matter of pure legume and total (grass plus legume) yield as an average of seeding dates and methods.

RESULTS AND DISCUSSION

Stands

Grass suppression was vital for seedling establishment and yields when sod seeding red clover or birdsfoot trefoil into sown grasses (BG, RCG, OG) or a weedy quackgrass sod. Four cuts were as effective as the herbicide pronamide in suppressing the sown grasses for good seeding-year stands of both legumes (Tables 1 and 3). Two cuts were less effective but better than 0 cuts. Pronamide was more effective than the cutting treatments, however, in suppressing quackgrass on the droughty soil in Exp. 4 (Tables 7 and 8). In comparison to the sown grasses, quackgrass is a noxious perennial weed with aggressive rhizomatous growth making it difficult to eradicate. Quackgrass competition to the introduced legumes was not reduced adequately by 2 cuts for better stand establishment and yields.

Legume stands in the year after seeding of 26-Mar.-broadcast seedings were equally good as 21-Apr.-drilled seedings into the sown grasses (Tables 1 and 3). These year-after-seeding counts were obtained at a time that reflected more accurately the complete grass suppression treatments than the year-of-seeding counts. All seeding-year counts were made three months after seeding, after only 1 and 2 cuts, for the 2- and 4-cut treatments, respectively.

After only two of the scheduled four cuttings during the seeding year, better red clover stands were established in all sown grass sods, compared to no grass suppression. Better seeding-year red clover stands were also obtained when competition to the grasses was reduced by cutting twice, compared to only once, except with drilled seedings in bromegrass.

Seeding-year drilled seedings of red clover were consistently better than broadcast seedings in sown grasses in reed canarygrass sods only. Various other treatments were benefited initially by drilling in sown grasses but stand decline measured in the year after seeding indicated no long-term advantage of drilling the seed in the sod, compared to broadcasting it on the surface. Seeding-year stands of red clover in Exp. 3 were better when drilled into quackgrass sods compared to broadcasting the seed on the surface. This stand advantage was still evident a year later in the 4-cut and herbicide-suppression treatments (Table 5). Trefoil seedings in all experiments were equally good when the seed was drilled in the sod or broadcast on the surface (Tables 3, 5, and 7).

The early broadcast seeding of 26 Mar. was made with better moisture and provided a greater growth advantage towards the competitive early grass growth. Drilled seedings were made four weeks later on 21 Apr. when grasses were beginning to grow and the advantage of seed placement in the soil was reduced by greater grass competition. These findings are consistent with previous work showing the lack of differences in stand establishment between early (31 Mar.) broadcast and later (15 Apr.) drilled seedings of trefoil (Holland, 1980).

Red clover benefited from the early-spring rains equally as well as trefoil but the poorer stands of the 26 Mar. seedings than of the later 21 Apr. drilled seedings were likely due to freezing injury to the red clover seedlings. Trefoil stands were similar from both seedings dates which is consistent with data (Holland and Tesar, 1983) showing that trefoil will tolerate freezing temperatures likely to be encountered in March more readily than red clover.

Red clover stands were not expected to decline sharply in the year after seeding as stand depletion of this species is not usually noticeable until the third growing season. Averaged over seeding and suppression treatments, the stand decline was 52% over all sown grass species (Table 1) with a decline of 36, 57, and 61% for seedings in bromegrass, reed canarygrass and orchardgrass sods, respectively. This relative percentage decline was a clear indicator of the differing competitive growth of the grass species toward the introduced clover seedlings. Averaged trefoil stand decline in the same period was 33% over all sown species with a decline of 32 and 33% for reed canarygrass and orchardgrass sods, respectively (Table 3). Red clover stands declined 64% when seeded into quackgrass sods, which was a 12% greater decline than from seedings in sown grasses (52%). Red clover declined 65% in Exp. 3 (Table 5) and 63% in Exp. 4 (Table 6). Trefoil stand decline of 24% in quackgrass was 9% less than the stand decline in sown grasses (33%). Trefoil declined 16% in Exp. 3 (Table 5) and 33% in Exp. 4 (Table 7).

Yields

Yield of red clover in the year after seeding (1981) was equally good when the sown grasses were suppressed with a herbicide or by 4 cuts (Table 2). Legume yield averaged over seeding methods and grasses clearly showed the effectiveness of the suppression treatments. Compared to 0 cuts, 564 and 755% more red clover was produced when the grass competition was reduced by 2 and 4 cuts, respectively. These yields showed much more accurately the differences between the grass suppression treatments than did the seeding year counts. Reduced competition from the grasses produced larger, more vigorous legume plants and consequently higher yields. Average red clover yields in the second year after seeding (1982) were 48% better from the herbicide treated swards (3.7 t ha^{-1}) than in the 4-cut suppression treatment (2.5 t ha^{-1}).

The yield difference in the first year after seeding was only 5% better with the herbicide treatment but total forage (grass plus red clover) produced in both years from either treatment did not differ significantly (Table 2). This reduction in yield in the third year of growth provides strong evidence for the recommendation of seeding red clover, a short-lived perennial, into pastures every second year in order to maintain a satisfactory stand.

Herbicide suppression of a quackgrass sod (Exp. 3) which was less dense than in Exp. 4 did not increase red clover yields more than the cutting treatments (Table 6) but it did reduce the greater quackgrass competition in Exp. 4 to produce substantially higher yields (Table 8). Moisture was not limiting on the heavier soil of Exp. 3 but, on the extremely drought-prone, coarse-textured soil of Exp. 4 grasses suppressed with 4 cuts competed for water at the expense of high legume yields. In this trial, both broadcast and drilled trefoil seedings were made on the same date because melting snow caused flooding along one edge of the experimental area during the earlier date. Even though the land slope was less than 2%, greater soil moisture retention and subsequent availability to the trefoil seedlings was suspected to have helped produce stands and yields that were equally good by each seeding method.

Average dry matter yield of trefoil in sown grasses was low (2.7 t ha^{-1}) in the year after seeding, but more than doubled the following year (5.5 t ha^{-1}) (Table 4). This is in contrast to red clover which declined 48% in yield over the same period as it is less perennial in nature than trefoil. Herbicide suppression helped produce better yields of trefoil than 0 or 2 cuts in all cases except in broadcast seedings into an orchardgrass sod. The reduced effectiveness of pronamide on orchardgrass suppression has been shown (Holland, 1980; Triplett et al., 1977) and did not adequately suppress this grass for a high legume yield. A distinct two-year yield advantage for trefoil was obtained by reducing the grass competition by cutting twice (8.9 t ha^{-1}) compared to no cuts (4.6 t ha^{-1}). Trefoil yield increases obtained from suppression treatments of the sown grasses in comparison to 0 cuts were similar: 2 cuts—193%; 4 cuts—207%; and herbicide—230%.

Legume yields were excellent from all suppression treatments when seeded in a quackgrass sod on the fine-textured soil of Exp. 3 (Table 6). At the initiation of this study, 80% of the sod was quackgrass. Even with this high quackgrass content, the sward was less vigorous than anticipated and much more easily suppressed by a herbicide or cutting than similar stands at other locations. This was demonstrated by the lack of yield differences obtained between 2 and 4 cuts and zero suppression treatments in both 1981 and 1982. Yields from seedings made in the coarse-textured soil of Exp. 4 benefited much more by complete sod suppression with a herbicide (Table 8). Two cuts did not suppress the quackgrass sufficiently more than 0 cuts to produce better yields. Red clover yields were 264 and 407% higher from the 4-cut and herbicide-suppression treatments, respectively, when compared to 0 cuts. For the same treatments, trefoil yields were 356 and 511% better than with 0 cuts. Yield decline of both legumes in the second year after seeding was attributed to the droughty soil conditions of this site.

As a low-cost method of pasture improvement with sown grasses, broadcasting red clover or birdsfoot trefoil seed on the surface in early spring and reducing competition during the seeding year by adequate mowings or rotational grazing of the grasses is a very satisfactory method for stand establishment and subsequent good yields.

With greater competition from a quackgrass sod than from any sown grasses, the need for better, more complete suppression increases. Vigorous quackgrass swards were suppressed more effectively by pronamide than by the most frequent defoliation treatment of 4 cuts. Suppression by cutting particularly in more droughty soils of a quackgrass sod, is not adequate for good establishment of red clover or birdsfoot trefoil.

SUMMARY AND CONCLUSIONS

Four field experiments were conducted by sod seeding red clover and birdsfoot trefoil into bromegrass, reed canarygrass, orchardgrass, and quackgrass swards. Seedings were made by broadcasting the seed on the surface on 26 Mar. or drilling it into the sod on 21 Apr. Competition from the grasses to the introduced legume seeds was reduced by the fall-applied herbicide pronamide or by 0, 2, or 4 cuts of the grasses at various times after seeding. It was determined from this study that:

1. Suppression of sown-grass sods by cutting, was as effective as herbicide suppression in stand establishment and subsequent good yields when sod seeding red clover and birdsfoot trefoil.

2. Sown grasses were suppressed more consistently by 4 cuts than by pronamide for good legume establishment.

3. Dense, vigorous quackgrass sods required suppression by a herbicide for successful introduction of legume species but competition from a less dense quackgrass sod was controlled successfully by four defoliations for good legume establishment.

4. Initial red clover stand establishment was benefited by drilling the legume seed in the grass sod, but yields and stand perisistence were similar from either broadcast or drilled seedings.

5. Birdsfoot trefoil seedings were equally good when broadcast early on 26 Mar. or drilled four weeks later on 21 Apr.

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Table 1. Stand density of red clover 3 and 15 months after sod seeding into 3 grass swards that were suppressed with a herbicide (check) or different cutting frequencies (Exp. 1).

Grass Suppression	Bromegrass		Reed canarygrass		Orchardgrass		Average		Stand loss
1980	1980	1981	1980	1981	1980	1981	1980	1981	1980 to 1981
	Plants m^{-2}								%
	Broadcast 26 Mar. 1980								
0 cuts	104	61	104	31	82	20	97	37	62
2 cuts	98	70	132	62	102	46	111	59	47
4 cuts	136	87	169	79	130	65	145	77	47
Herbicide	126	79	182	86	115	51	141	72	49
Average	115	74	147	65	107	46	123	62	50
	Drilled 21 Apr. 1980								
0 cuts	84	61	123	38	122	26	110	42	62
2 cuts	138	85	170	65	108	45	139	65	53
4 cuts	148	99	230	100	155	63	178	87	51
Herbicide	166	95	216	103	134	59	172	86	50
Average	134	85	185	77	130	48	150	70	53
	Average of Broadcast and Drilled								
0 cuts	94	61	114	35	102	23	103	40	61
2 cuts	118	78	151	64	105	46	125	63	50
4 cuts	142	93	200	90	143	64	162	82	49
Herbicide	146	87	199	95	125	55	157	79	50
Average	125	80	166	71	119	47	137	66	52

$LSD_{(0.05}$

1980	1981	Between	Within
61	38	Grasses	The same seeding method and level of suppression
33	NS	Seeding methods	The same grass and level of suppression
26	26	Suppression tmts	The same grass and seeding method

Table 2. Yield of red clover (red clover plus grass in parenthesis) sod seeded on two dates into three swards that were suppressed with a herbicide (check) or by different cutting frequencies (Exp. 1).

Grass Suppression	Bromegrass			Reed canarygrass			Orchardgrass			Average		
1980	1981	1982	Total	1981	1982	Total	1981	1982	Total	1981	1982	Total
	$t\ ha^{-1}$											
	Broadcast 26 Mar. 1980											
0 cuts	1.5	2.5	4.0	0.9	2.4	3.3	0.8	2.5	3.3	1.1	2.5	3.6
2 cuts	6.0	2.3	8.3	6.1	2.5	8.6	6.1	2.1	8.2	6.1	2.3	8.4
4 cuts	8.5	2.2	10.7	9.3	2.4	11.7	7.5	1.7	9.2	8.4	2.1	10.5
Herbicide	8.9	4.4	13.3	8.9	3.1	12.0	7.5	2.2	9.7	8.5	3.2	11.7
Average	6.2	2.8	9.1	6.3	2.8	8.9	5.5	2.1	7.6	6.0	2.5	8.6
	Drilled 21 Apr. 1980											
0 cuts	0.7	2.5	3.2	0.7	2.9	3.6	1.5	3.1	4.6	1.0	2.8	3.8
2 cuts	6.5	3.0	9.5	5.9	3.3	9.2	6.1	2.9	9.0	6.2	3.1	9.3
4 cuts	8.5	3.1	11.6	8.2	3.4	11.1	7.7	2.8	10.5	8.1	2.8	10.9
Herbicide	8.9	4.9	13.8	9.1	4.5	13.6	8.5	3.3	11.8	8.8	4.2	13.0
Average	6.1	3.4	9.5	6.0	3.5	9.5	6.0	3.0	9.0	6.0	3.2	9.3

Table 2 cont.

Average of broadcast and drilled

0 cuts	1.1 (5.8)	2.5 (7.2)	3.6 (13.0)	0.8 (4.7)	2.7 (6.8)	3.5 (11.5)	1.2 (4.8)	2.8 (8.0)	4.0 (12.8)	1.1 (5.1)	2.7 (7.5)	3.7 (12.6)
2 cuts	6.3 (9.2)	2.7 (8.9)	8.9 (18.1)	6.0 (8.8)	2.9 (8.4)	8.9 (17.2)	6.1 (8.8)	2.5 (9.1)	8.6 (17.9)	6.2 (8.9)	2.7 (8.8)	8.9 (17.7)
4 cuts	8.5 (9.6)	2.7 (8.6)	11.2 (18.2)	8.8 (9.5)	2.9 (7.2)	11.4 (16.7)	7.6 (9.4)	2.3 (7.7)	9.9 (17.1)	8.3 (9.5)	2.5 (7.8)	10.7 (17.3)
Herbicide	8.9 (9.5)	4.7 (8.5)	13.6 (18.0)	9.0 (9.6)	3.8 (8.1)	11.8 (17.7)	8.0 (9.5)	2.8 (8.4)	10.8 (17.9)	8.7 (9.5)	3.7 (8.3)	12.4 (17.8)
Average	6.2 (8.5)	3.1 (8.4)	9.3 (16.9)	6.2 (8.2)	3.1 (7.6)	9.2 (15.8)	5.8 (8.1)	2.6 (8.3)	8.3 (16.4)	6.0 (8.3)	2.9 (8.1)	8.9 (16.4)

$LSD_{(0.05)}$

1981	1982	Between	Within
NS	NS	Grasses	The same seeding method and level of suppression
NS	1.0	Seeding methods	The same grass and level of suppression
1.1	1.3	Suppression tmts	The same grass and seeding method

Table 3. Stand density of birdsfoot trefoil 3 and 15 months after sod seeding into two grass swards that were suppressed with a herbicide (check) or different cutting frequencies (Exp. 2).

Grass Suppression 1980	Reed canarygrass 1980	Reed canarygrass 1981	Orchardgrass 1980	Orchardgrass 1981	Average 1980	Average 1981	Stand Loss 1980 to 1981
	Plants m^{-2}						%
			Broadcast 26 Mar. 1980				
0 cuts	116	54	95	51	106	53	50
2 cuts	120	93	128	96	124	97	22
4 cuts	187	116	150	114	167	115	31
Herbicide	171	124	115	78	143	101	29
Average	148	97	122	85	135	91	33
			Drilled 21 Apr. 1980				
0 cuts	109	57	102	41	106	49	54
2 cuts	128	83	126	92	127	88	31
4 cuts	153	118	133	99	143	109	24
Herbicide	137	94	143	93	140	94	33
Average	132	88	126	81	129	85	34
			Average of Broadcast and Drilled				
0 cuts	113	56	99	46	106	51	52
2 cuts	124	90	127	94	126	92	27
4 cuts	170	117	142	107	156	112	28
Herbicide	154	109	129	89	142	99	30
Average	140	93	124	83	132	88	33

$LSD_{(0.05)}$

1980	1981	Between	Within
NS	NS	Grasses	The same seeding method and level of suppression
NS	NS	Seeding methods	The same grass and level of suppression
43	48	Suppression tmts	The same grass and seeding method

Table 4. Yield of birdsfoot trefoil (trefoil plus grass in parenthesis) sod seeded on two dates into two grass swards that were suppressed with a herbicide (check) or different cutting frequencies (Exp. 2).

Grass Suppression	Reed canarygrass			Orchardgrass			Average		
1980	1981	1982	Total	1981	1982	Total	1981	1982	Total
	t ha^{-1}								
	Broadcast 26 Mar. 1980								
0 cuts	0.5	3.3	3.8	0.7	5.0	5.7	0.6	4.2	4.8
2 cuts	2.6	5.9	8.4	3.5	6.4	9.8	3.1	6.2	9.3
4 cuts	3.0	5.4	8.4	3.9	6.9	10.8	3.5	6.2	9.7
Herbicide	4.7	5.7	10.4	3.6	5.6	9.2	4.2	7.5	11.7
Average	2.7	5.1	7.8	2.9	6.0	8.9	2.7	5.6	8.3
	Drilled 21 Apr. 1980								
0 cuts	0.5	3.9	4.3	0.4	3.9	4.3	0.5	3.9	4.4
2 cuts	2.2	6.4	8.7	2.5	6.4	8.9	2.4	6.4	8.4
4 cuts	3.4	6.1	9.4	3.3	5.7	9.0	3.4	5.9	9.3
Herbicide	4.6	4.7	9.4	3.7	5.7	9.4	4.2	5.2	9.4
Average	2.7	5.3	7.9	2.5	5.4	7.9	2.6	5.4	8.0
	Average of broadcast and drilled								
0 cuts	0.5 (3.3)	3.6 (6.2)	4.1 (9.5)	0.6 (3.3)	4.5 (7.8)	5.0 (11.1)	0.6 (3.3)	4.1 (7.0)	4.6 (10.3)
2 cuts	2.4 (5.6)	6.2 (8.6)	8.6 (14.2)	3.0 (5.9)	6.4 (9.3)	9.4 (15.2)	2.8 (5.7)	6.3 (8.9)	8.9 (14.6)
4 cuts	3.2 (6.1)	5.8 (8.4)	8.9 (14.5)	3.6 (6.6)	6.3 (9.3)	9.1 (15.9)	3.5 (6.4)	6.1 (8.8)	9.5 (15.2)
Herbicide	4.7 (7.1)	5.2 (8.5)	9.9 (15.6)	3.7 (6.1)	5.7 (9.2)	9.3 (15.3)	4.2 (6.6)	6.4 (8.9)	10.6 (15.5)
Average	2.7 (5.5)	5.2 (7.9)	7.9 (13.4)	2.7 (5.5)	5.7 (8.9)	8.4 (14.4)	2.7 (5.5)	5.5 (8.4)	8.2 (13.9)

$LSD_{(0.05}$

1981	1982	Between	Within
NS	NS	Grasses	The same seeding method and level of suppression
0.8	NS	Seeding methods	The same grass and level of suppression
0.9	1.5	Suppression tmts	The same grass and seeding method

Table 5. Stand density of red clover and birdsfoot trefoil 3 and 15 months after sod seeding into an 80% quackgrass sward that was suppressed with a herbicide (check) or different cutting frequencies (Exp. 3).

Grass Suppression 1980	Red clover 1980	Red clover 1981	Birdsfoot trefoil 1980	Birdsfoot trefoil 1981
	Plants m^{-2}			
	Broadcast 26 Mar. 1980			
0 cuts	93	62	104	92
2 cuts	125	80	98	85
4 cuts	131	94	126	107
Herbicide	113	88	133	100
Average	115	81	115	96
	Drilled 21 Apr. 1980			
0 cuts	131	81	95	92
2 cuts	168	96	105	90
4 cuts	201	139	144	115
Herbicide	196	113	145	117
Average	174	107	122	103
	Average of Broadcast and Drilled			
0 cuts	112	72	100	92
2 cuts	147	88	102	88
4 cuts	166	117	135	111
Herbicide	155	101	139	109
Average	145	94	119	100

$LSD_{(0.05)}$

1980	1981	Between	Within
NS	NS	Legumes	The same seeding method and level of suppression
35	22	Seeding methods	The same legume and level of suppression
29	19	Suppression tmts	The same legume and seeding method

Table 6. Yield of red clover and birdsfoot trefoil sod seeded on two dates into an 80% quackgrass sward that was suppressed with a herbicide (check) or different cutting frequencies (Exp. 3).

Grass Suppression 1980	Red clover 1981	Red clover 1982	Red clover Total	Birdsfoot trefoil 1981	Birdsfoot trefoil 1982	Birdsfoot trefoil Total
	$t\ ha^{-1}$					
			Broadcast 26 Mar. 1980			
0 cuts	8.8	7.7	16.5	7.2	9.2	16.4
2 cuts	9.6	7.1	16.7	8.0	8.6	16.6
4 cuts	9.6	7.5	17.1	7.5	8.1	15.6
Herbicide	9.9	7.7	17.6	8.4	9.3	17.7
Average	9.5	7.5	17.0	7.8	8.8	16.6
			Drilled 21 Apr. 1980			
0 cuts	9.1	7.7	16.9	7.9	9.4	17.3
2 cuts	9.6	7.9	17.5	7.9	8.5	16.4
4 cuts	10.2	8.0	18.2	7.5	8.8	16.3
Herbicide	10.0	8.3	18.3	8.8	9.0	17.8
Average	9.8	8.0	17.7	8.0	9.0	17.0
			Average of Broadcast and Drilled			
0 cuts	9.0	7.7	16.7	7.5	9.3	16.9
2 cuts	9.6	7.5	17.1	8.0	8.6	16.5
4 cuts	9.9	7.8	17.7	7.5	8.5	16.0
Herbicide	10.0	8.0	18.0	8.6	9.2	17.8
Average	9.7	7.8	17.4	7.9	8.9	16.8

$LSD_{(0.05)}$

1981	1982	Between	Within
0.9	NS	Legumes	The same seeding method and level of suppression
NS	NS	Seeding methods	The same legume and level of suppression
0.8	NS	Suppression tmts	The same legume and seeding method

Table 7. Stand density of red clover and birdsfoot trefoil 3 and 15 months after sod seeding into a 90% quackgrass sward that was suppressed with a herbicide (check) or different cutting frequencies (Exp. 4).

Grass Suppression 1980	Red clover 1980	Red clover 1981	Birdsfoot trefoil 1980	Birdsfoot trefoil 1981
	Plants m^{-2}			
	Broadcast 1980			
	26 Mar.		21 Apr.	
0 cuts	8	3	21	8
2 cuts	6	5	15	9
4 cuts	23	18	57	42
Herbicide	78	59	40	26
Average	29	22	33	22
	Drilled 21 Apr. 1980			
0 cuts	29	15	17	11
2 cuts	58	33	30	17
4 cuts	60	34	66	37
Herbicide	111	57	66	50
Average	65	35	45	29
	Average of Broadcast and Drilled			
0 cuts	19	9	19	10
2 cuts	32	19	23	13
4 cuts	42	26	62	40
Herbicide	95	58	53	38
Average	47	29	39	26

$LSD_{(0.05)}$

1980	1981	Between	Within
NS	NS	Legumes	The same seeding method and level of suppression
36	NS	Seeding methods	The same legume and level of suppression
29	27	Suppression tmts	The same legume and seeding method

Table 8. Yield of red clover and birdsfoot trefoil sod seeded on two dates into a 90% quackgrass sward that was suppressed with a herbicide (check) or by different cutting frequencies (Exp. 4).

Grass Suppression 1980	Red clover 1981	Red clover 1982	Red clover Total	Birdsfoot trefoil 1981	Birdsfoot trefoil 1982	Birdsfoot trefoil Total
	t ha^{-1}					
	Broadcast 1980					
	26 Mar.			21 Apr.		
0 cuts	1.3	0.2	1.5	0.9	0.3	1.2
2 cuts	2.0	0.3	2.3	1.9	1.5	3.4
4 cuts	3.6	0.3	3.9	3.6	2.4	6.0
Herbicide	6.3	2.0	8.3	3.4	2.3	5.7
Average	3.3	0.7	4.0	2.5	1.6	4.1
	Drilled 21 Apr. 1980					
0 cuts	1.5	0.3	1.8	0.8	0.1	0.9
2 cuts	3.1	0.4	3.5	1.0	0.7	1.7
4 cuts	3.7	0.3	4.0	2.8	3.0	5.8
Herbicide	5.0	1.9	6.9	4.9	3.5	9.2
Average	3.3	0.7	4.0	2.4	1.9	4.3
	Average of Broadcast and Drilled					
0 cuts	1.4	0.3	1.7	0.9	0.2	1.1
2 cuts	2.6	0.4	3.0	1.5	1.1	2.6
4 cuts	3.7	0.3	4.0	3.2	2.7	5.9
Herbicide	5.7	2.0	7.7	4.6	2.9	7.5
Average	3.3	0.7	4.0	2.5	1.8	4.3

$LSD_{(0.05)}$

1981	1982	Between	Within
NS	NS	Legumes	The same seeding method and level of suppression
NS	NS	Seeding methods	The same legume and level of suppression
1.9	1.7	Suppression tmts	The same legume and seeding method

CHAPTER 4

SURVIVAL OF THREE FORAGE LEGUMES SEEDED IN CONTACT WITH PHOSPHORUS AND POTASSIUM

ABSTRACT

Pasture improvement with the introduction of high producing legumes into an existing grass sward requires excellent management during establishment. Fertilizer applied to promote maximum early vigorous growth must be placed, when sod seeding, in contact with seeds in a single slit in the sod. Injury from fertilizer when placed in contact with seeds of corn *(Zea mays L.)* and small grains has been well documented but injury to forage legume seeds has not been well studied. Greenhouse trials were conducted with alfalfa *(Medicago sativa L.)*, red clover *(Trifolium pratense L.)* and birdsfoot trefoil *(Lotus corniculatus L.)* seeded in contact with various rates of P and K fertilizer to determine injury.

Phosphorus reduced seedling survival more severely than similar rates of K. Extremely low fertilizer-band pH was considered the primary cause of poor stand survival from P in contact with the seeds. To apply similar quantities of P and K, 2.5 times more commercial P fertilizer was required. This larger bulk of material produced a

more constant distribution pattern of fertilizer which also likely contributed to the lower seedling survival when P was applied. Legume stands were not reduced by rates of K lower than 35.5 kg ha^{-1} except for red clover with K at 11.5 and 23.0 kg ha^{-1}.

Legume yields were reduced by both fertilizers at rates higher than those normally recommended for field seedings. A sharper decline in yield, with increased fertilizer application, was obtained with P compared to K.

Additional index words: *Medicago sativa L.*, *Trifolium pratense L.*, *Lotus corniculatus L.*, pasture renovation, sod seeding, poor germination, seedling injury, fertilizer injury.

INTRODUCTION

Of the estimated 42 million hectares of permanent pastures in the United States, almost half can be improved significantly simply by proper grazing, fertilization and weed control (Baylor, 1975). The cropland used for hay and pasture approximates another 30 million hectares according to the USDA conservation-needs inventory. A large portion of these grassland areas could be maintained at a more productive level by pasture renovation. This involves the introduction of a more productive forage legume into a grass sward without the growing of an intervening crop. Complete tillage, followed by reseeding, has been the most widely accepted and successful method of pasture improvement (Tesar and Hildebrand, 1975). However, in hilly, erodible areas, reduced tillage or sod seeding of forage legumes has successfully prevented erosion and greatly increased pasture productivity.

Reducing competition from the grasses to the introduced legumes has been the most important factor in making sod seedings. Fertilization of small-seeded legumes at seeding has also been recognized for many years as being important for good early growth (Cook and Millar, 1944; Tesar et al., 1954). When fertilizer placement studies were started in the 1920s, according to Mortvedt (1976) the problems were much different from those of today. Low analysis fertilizers were applied at rates up to 330 kg ha^{-1} close to, or in contact with the seed without causing any problems. Today, the average nutrient content of fertilizers and rates of application are higher. Mortvedt maintains that the likelihood of damage from current high analysis fertilizers placed too near or in contact with the seed is much higher now. Duell (1976) reviewed the literature on P fertilization for forage establishment and found general agreement that legume seedlings are usually less able than grasses to obtain P from low soil-P concentrations associated with broadcast fertilizer applications. Seedling growth of both grasses and legumes is enhanced by placing P in concentrated bands directly underneath the seed row (Sheard et al., 1971; Tesar et al., 1954). These researchers found that if the fertilizer band was 2 or 3 cm to the side of the seed row, early growth of alfalfa seedlings was significantly reduced. Pasture renovation with seedings drilled in the sod has necessitated the placement of fertilizer with the seed for maximum stimulation and early growth of legume seedlings. Machinery adapted to place seed and fertilizer separately into untilled soils has not been commercially available and the physical firmness of these seedbeds has added to the difficulties of separate placement of seed and fertilizer.

Considerable research has been conducted on the effects of various types and quantities of fertilizer placed in contact with seeds of corn, small grains and various other crops. The overall hesitancy of workers to conclude that seed in contact with fertilizer is beneficial and without problems was well summarized by Mortvedt (1976). He stated that if the resulting fertilizer placement was too close to the seed, reduced seedling emergence may result. He further added that placement of small amounts of fertilizers in the seed row is not widely used because of possible delays or decreases in seed germination and decreased stands. Cook (1957) emphasized that young seedlings should be well fertilized to promote rapid, vigorous growth, but to avoid injury to most crops, fertilizers should not be placed in contact with seeds. In giving recommendations to producers on how to successfully sod seed birdsfoot trefoil and alfalfa, Tesar (1980) suggested, based on unpublished field trials, that 22 kg ha^{-1} of P could be added in contact with the seed without injury. Duell (1963), however, concluded from his work that both alfalfa and trefoil showed reduced emergence when seeds were close to concentrations of soluble fertilizers while moisture was low.

This study was conducted under closely controlled conditions in the greenhouse to determine how injurious various rates of the most commonly used commercial P and K fertilizers would be to three forage legumes when placed in contact with the seed at the time of seeding.

MATERIALS AND METHODS

Alfalfa *(Medicago sativa L.)*, red clover *(Trifolium pratense L.)*, and birdsfoot trefoil *(Lotus corniculatus L.)* were seeded in contact with various rates of P and K fertilizer under controlled conditions in the greenhouse. Treatments were replicated four times in a split-plot, randomized, complete block design. Pots were moved twice weekly within each block in a directed rotation to minimize light effects. A Brookston loam (fine-loamy, mixed mesic Typic Agriaquolls) soil of pH 7.3 was placed in 22.5-cm-diameter pots and prepared for seeding by forming a single crease 0.5 cm deep across each pot (Fig. 2). A specially designed vacuum-operated seeder placed 22 seeds 1 cm apart in the pre-formed creases in the soil in each pot. Commercial-grade fertilizer, (0-46-0 and 0-0-60), without additional grinding or pulverizing, was distributed evenly in the soil crease. Rates of fertilizer were calculated based on the surface area of the pots and adjusted to equal applications in kg ha^{-1} in rows spaced at 17.5 cm. Rates of P were 0, 12, 24, 36, 48, 60, 72, and 96 kg ha^{-1}. Rates of K were 0, 11.5, 23.0, 34.5, 46.0, 69.0, 92.0, and 138.0 kg ha^{-1}. The fertilizer was added after seeding to prevent the deflection and uneven spacing of the seeds by the fertilizer granules and crystals. The legume seed was inoculated prior to seeding with a slurry of appropriate rhizobia inoculum. Additional dry inoculum was added in the soil crease at seeding. Measured quantities of water containing a fungicide were added every second day for the first 20 days to facilitate uniform fertilizer dilution and minimize damping off disease due to *Pythium spp*.

Determinations of pH were made 3 and 10 days after seeding in situ on the fertilizer band in the pots containing red clover. A Beckman 3560 digital meter with combination electrode was used to obtain pH values by inserting the electrode into the area of banded seed and fertilizer immediately after applying a measured amount of de-ionized water to the surface of the pot. The lowest, stable pH value averaged from two readings per pot was obtained. Seedling counts were made every 5 days up to 25 days after seeding with a final determination at 90 days. At this time, all top growth was harvested, dried with forced air at 65 C for 48 hours, and weighed. Yields are reported in grams of dry matter per pot.

RESULTS AND DISCUSSION

Seedling survival increased up to 10 to 15 days after seeding in all except the four highest rates of P, and then showed no further increase (Tables 1 and 2). Red clover was somewhat more tolerant of being in contact with P than alfalfa or trefoil but was less tolerant than alfalfa or trefoil when in contact with K.

The lowest rate of P (12 kg ha^{-1}) placed in contact with the seed significantly reduced 90-day seedling survival of all three legumes (Table 1). Stand survival was best when no P was added. Averaged over legumes the survival decreased with increases in rates of P in kg ha^{-1}: 0—93% > 12—74% > 24—36% > 36—17%. Only a few seedlings survived when in contact with 48 and 60 kg of P; none survived the 82- and 96-kg rates. At similar rates, K in contact with these forage legume seeds did not reduce seedling survival nearly as much as P. Legume stands were equally good at 0, 11.5, 23.0, or 34.5 kg of K ha^{-1} except at 11.5 and 23.0 kg where the red clover stand was significantly reduced in comparison to that obtained with no fertilizer (Table 2). Averaged over legumes, seedling survival decreased with increased rates of K in kg ha^{-1}: 0—93% > 11.5—85% > 46—77% > 69—59% > 92—18% > 138—7%. The salt index of KCl fertilizer per unit of nutrient is over nine times higher than that of concentrated superphosphate according to Radar et al. (1943). This clearly indicates that the lower survival rate of legumes in contact with P compared to those in contact with K was not caused by fertilizer salt injury.

Rates of P up to 48 kg ha^{-1} are recommended as safe to apply in a band below the seed in most Michigan soils when seeding forage legumes (Warncke and Christenson, 1980). Almost twice this amount is the maximum P recommended for broadcast application at one time on soils with the lowest amount of P. This contrasts with maximum recommended rates of K at 46 kg ha^{-1} in a band under the seed and 370 kg K ha^{-1} broadcast, for high production on K-deficient soils. The Michigan State University Soil Testing Laboratory tested 24,631 soil samples during 1982. Fifteen percent of these samples were tested for producers requesting recommendations for suitable fertilizers to be applied when making new alfalfa seedings (Meints, 1983). Only 45% of all the samples tested for alfalfa establishment required the addition of P. Twenty percent required P at 12 kg ha^{-1}, 15% needed 36 kg ha^{-1}, and 10% required rates higher or equal to the highest "safe" recommended rate. If producers had made sod seedings of alfalfa and added P in contact with the seed according to their soil test results, based on data from this greenhouse experiment, they would have sustained a stand loss of 19, 57, and 76% when applying 12, 24, and 36 kg ha^{-1} of P, respectively (Table 1). A 20% stand reduction would not be detected readily in field seedings and even a 50% stand loss would be difficult to detect without having comparable non-fertilized strips in each seeding.

Field seedings on a fine-textured soil have been made, however, with rates of P as high as 24 kg ha^{-1} in contact with legume seeds (Tesar, 1978) but it was not reported how many seedlings were killed by P. Figure 3 shows placement of seed and fertilizer granules in field seedings made by a commercial drill. The speed of the seeding equipment produced a scattered distribution of seed and fertilizer and likely avoided serious seedling injury through lack of contact. In firmer, more root-bound sods, the slit where seed and fertilizer are placed together in the soil is usually more closed, particularly when the soil is moist and high in clay, thereby producing a greater likelihood of injury.

Blaser and Kimbrough (1972) state that applications of K for forage establishment should be low to avoid interference with germination from high soluble salts and indicate ratios of 1P:1K have given good results. In the experiment reported here, reduced stand survival when K was palced in contact with the legume seeds was expected because of the high fertilizer salt content but stand depletion was no greater with similar rates of K than that from the P fertilizer. Most soils, however, require three to four times the amount of K to P fertilizer for maximum growth of legumes and recommendations normally reflect much higher rates of K than P being applied when seeding legumes.

Guttay (1957) concluded from his work with fertilizers in contact with seeds of wheat and oats that the P content of fertilizers was just as important as N and K in producing seed injury, but he could not identify the major constituent of P fertilizers responsible for the seed injury. Readings of pH in the fertilizer band obtained 3 and 10 days after seeding in the trial reported here showed that an extremely acid micro-environment was formed around the seeds with P fertilizer, but not with K (Fig. 1). A 1:1 water-fertilizer solution, equilibrated for one hour, produced pH readings of 3.0 for P, and 6.3 for the K fertilizers used in this trial. The saturated solution from a moistened granule of P fertilizer has been shown to be as acid as pH 1.48 (Lindsay et al., 1959). Lindsay and Stephenson (1959) found that when P was banded in a soil of pH 5.5, the pH of the soil samples from 0 to 10 mm from the band remained below 3.0 for at least 6 weeks. At this extremely low pH, these workers indicated that large amounts of Al, Fe, and Mn were brought into solution. High levels of any of these, particularly Al, for even a short period would have toxic effects on sensitive germinating seeds or seedlings. At similar rates of P and K, 2.5 times more commercial P fertilizer used in this study was added in comparison to the K fertilizer. This greater concentration of total fertilizer would have given a more even distribution of P and contributed to the overall stand decline with less probability for spaces between P granules than between K crystals. If both fertilizers had been pulverized before application, seedling injury and stand reduction from K would likely have been increased considerably. It was determined from additional control pots that many of the seedlings that survived high K rates grew between large fertilizer crystals. Fertilizers were not ground in order to simulate seeding and fertilizing under field conditions.

Yields of the three legumes 90 days after seeding were reduced at the higher rates of P and K which were greater than those recommended for making field seedings (Tables 3 and 4). A sharper decline in yield with increased fertilizer application was obtained with P compared to K. The higher yield from red clover was similar with both

P and K and was likely due to a greater tolerance of red clover than alfalfa or trefoil to reduced levels of light in the greenhouse (Gist and Mott, 1957).

The benefits of fertilizer, particularly P, to legume seedlings have been well documented. Faster and stronger root development and better initial growth are the most important benefits of adequate P to young seedlings. Producers of alfalfa are advised that even if the soil test indicates P is not necessary, the use of a starter fertilizer containing 12 kg P ha^{-1} placed 2 to 4 cm under the seed will help strong seedling development (Tesar, 1978). Data obtained here indicate, however, that when P at this rate was in contact with forage legume seeds as in sod seeding, stands were reduced by 19%. When the P rate was doubled from 12 to 24 kg ha^{-1}, however, survival decreased 38%—from 74 to 36%—a very severe stand loss.

Stand injury from P, therefore, can be expected on Michigan loam soils and very likely, on more coarse-textured soils if P is placed in contact with legume seeds. If P is recommended for seedling establishment when sod seeding in the field, better stands would be obtained by broadcasting this fertilizer before or after seeding rather than in contact with the seed.

SUMMARY AND CONCLUSIONS

Alfalfa, red clover, and birdsfoot trefoil were seeded under controlled conditions in the greenhouse in contact with various rates of P and K fertilizer. Seedling survival was more severely reduced by P than similar rates of K. From this study with commercial grade P (0-46-0) and K (0-0-60) fertilizer, it was determined that:

1. Phosphorus placed in contact with the seed reduced seedling survival at all levels of application.

2. Poor germination and survival when P was placed in contact with the seeds was caused by the extremely low fertilizer-band pH.

3. Potassium in contact with the seeds did not reduce legume stands at rates less than 34.5 kg ha^{-1}.

4. Red clover was more tolerant of P but less tolerant of K in contact with the seed than alfalfa or trefoil.

5. Phosphorus should not be applied in contact with forage legume seeds when sod seeding.

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Table 1. Percent survival of three forage legumes grown in the greenhouse after seeding in contact with various kg ha^{-1} of P.

Legumes	Days After Seeding 5	10	15	20	25	90
	%					
			0			
Alfalfa	90	86	88	88	88	88
Red clover	80	90	93	95	95	95
Trefoil	71	77	94	95	95	95
Average	80	84	92	93	93	93
			12			
Alfalfa	51	76	74	74	74	75
Red clover	58	84	79	77	83	76
Trefoil	43	68	70	69	69	70
Average	51	76	74	73	75	74
			24			
Alfalfa	15	39	39	34	33	34
Red clover	13	51	47	45	45	44
Trefoil	6	19	28	29	27	30
Average	11	36	38	36	35	36
			36			
Alfalfa	6	20	22	21	18	16
Red clover	5	28	26	21	20	20
Trefoil	3	5	17	17	17	14
Average	5	18	22	20	18	17
			48			
Alfalfa	3	12	10	8	8	8
Red clover	11	24	18	17	17	17
Trefoil	0	0	4	5	5	6
Average	5	12	11	10	10	10
			60			
Alfalfa	0	3	3	3	3	0
Red clover	0	7	5	4	4	3
Trefoil	0	0	0	0	0	0
Average	0	3	3	2	2	1
			72			
Alfalfa	0	0	0	0	0	0
Red clover	0	1	1	0	0	0
Trefoil	0	0	0	0	0	0
Average	0	0	0	0	0	0
			96			
Alfalfa	0	0	0	0	0	0
Red clover	0	0	0	0	0	0
Trefoil	0	0	0	0	0	0
Average	0	0	0	0	0	0
$LSD_{(0.05)}$						
Legumes	16	22	NS	NS	NS	NS
Fertilizer	14	14	13	13	14	12
Average	8	8	7	7	8	7

Table 2. Percent survival of three forage legumes grown in the greenhouse after seeding in contact with various kg ha^{-1} of K.

Legumes	Days After Seeding 5	10	15	20	25	90
	%					
			0			
Alfalfa	90	86	88	88	88	88
Red clover	80	90	93	95	95	95
Trefoil	71	77	94	95	95	95
Average	80	84	92	93	93	93
			11.5			
Alfalfa	87	95	91	88	89	92
Red clover	100	91	82	80	79	79
Trefoil	79	94	89	86	85	85
Average	89	93	87	85	84	85
			23.0			
Alfalfa	96	100	100	100	100	100
Red clover	82	90	82	81	80	76
Trefoil	80	100	98	96	95	94
Average	86	97	93	92	92	90
			34.5			
Alfalfa	51	92	91	88	89	93
Red clover	31	96	86	84	84	84
Trefoil	17	90	90	90	90	90
Average	33	93	89	87	88	89
			46.0			
Alfalfa	49	91	88	88	88	90
Red clover	24	76	70	67	64	61
Trefoil	9	85	82	81	81	81
Average	27	84	80	79	78	77
			69.0			
Alfalfa	9	59	58	58	59	62
Red clover	13	66	59	55	53	53
Trefoil	6	59	60	61	61	61
Average	9	61	59	58	58	59
			92.0			
Alfalfa	1	25	23	22	22	23
Red clover	0	16	11	11	11	11
Trefoil	0	15	22	21	20	19
Average	0	19	19	17	18	18
			138.0			
Alfalfa	0	13	13	13	13	13
Red clover	2	1	1	1	1	1
Trefoil	0	3	7	7	7	7
Average	1	6	7	7	7	7
$LSD_{(0.05)}$						
Legumes	16	NS	NS	NS	21	22
Fertilizer	14	14	13	13	14	12
Average	8	8	7	7	8	7

Table 3. Yield of three forage legumes obtained in the greenhouse 90 days after seeding in contact with various kg ha^{-1} of P.

P kg ha^{-1}	Alfalfa	Red clover	Trefoil	Average
	g/pot			
0	13.4	26.5	13.6	17.8
12	13.1	25.8	12.6	17.2
24	10.1	24.0	9.3	14.5
36	5.9	16.5	3.4	8.6
48	3.5	17.3	1.4	7.4
60	0.0	4.9	0.0	1.6
72	0.0	0.0	0.0	0.0
96	0.0	0.0	0.0	0.0
average	5.8	14.4	5.0	8.4
$LSD_{(0.05)}$	Between legumes at the same fertilizer rate			1.3
	Between fertilizer rates within the same legume			3.8

Table 4. Yield of three forage legumes obtained in the greenhouse 90 days after seeding in contact with various kg ha^{-1} of K.

P kg ha^{-1}	Alfalfa	Red clover	Trefoil	Average
	g/pot			
0.0	13.4	26.5	13.6	17.8
11.5	14.9	21.9	12.4	16.4
23.0	12.3	24.6	12.7	16.5
34.5	11.5	25.9	13.5	17.0
46.0	11.8	22.8	12.6	15.7
69.0	11.4	20.3	12.3	14.7
92.0	9.0	17.9	7.6	11.5
138.0	7.3	3.3	3.9	6.2
average	11.5	20.4	11.1	14.3
$LSD_{(0.05)}$	Between legumes at the same fertilizer rate			1.3
	Between fertilizer rates within the same legume			3.8

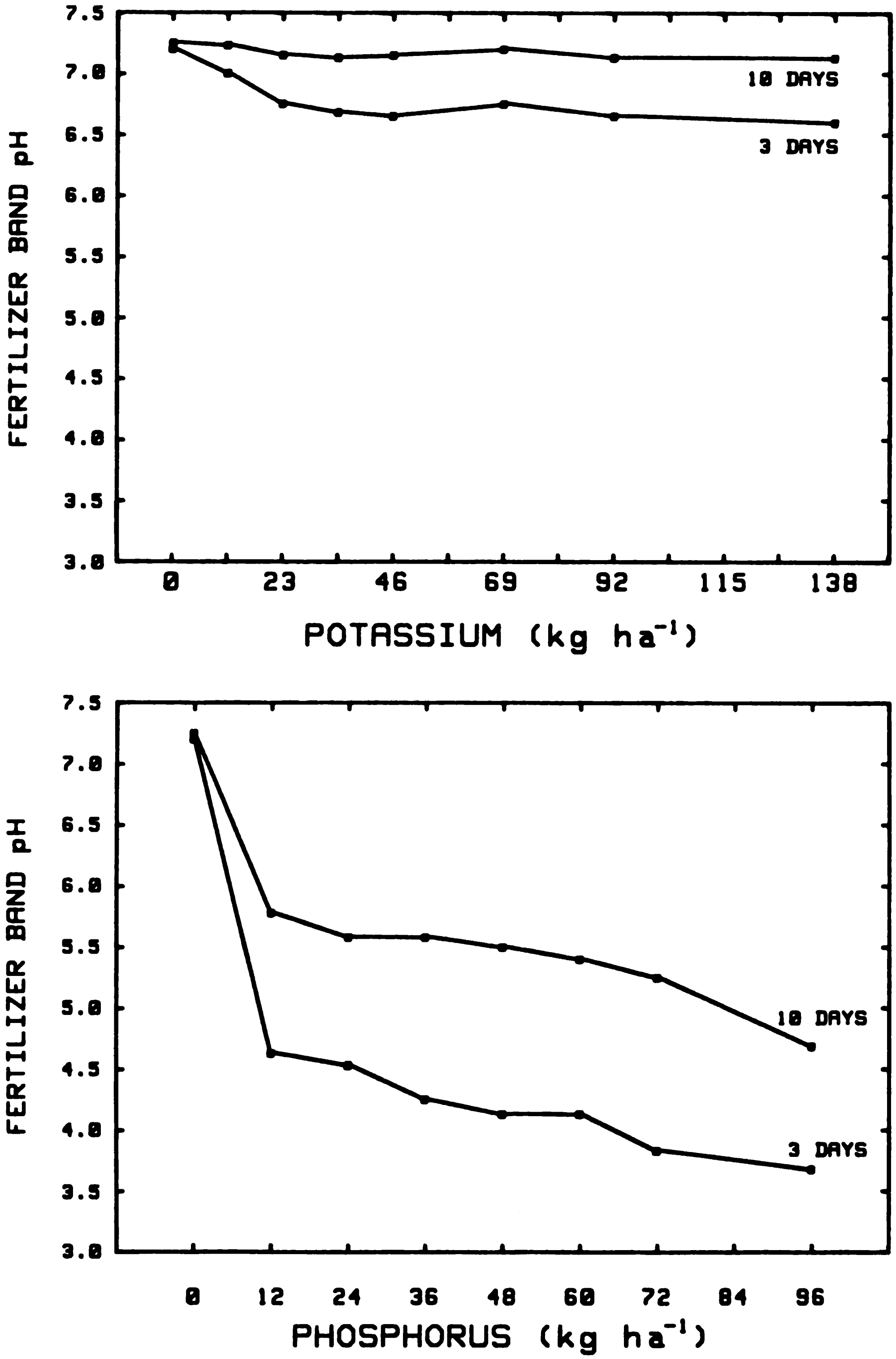

Fig. 1. Fertilizer-band pH sampled in situ 3 and 10 days after placing various rates of K (top) and P (bottom) in a Brookston loam soil.

Fig. 2. Soil crease (0.5 cm deep) for seed and fertilizer placement and vacuum-operated seeder.

Fig. 3. Placement of alfalfa seed and K fertilizer by commercial equipment when sod seeding into a herbicide-suppressed sod.

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