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Effects of Herbicides and Treatment Dates on the Establishment of Sod-seeded Red Clover, Birdsfoot Trefoil, and Alfalfa

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These experiments were conducted to investigate the effects of dates of seeding, herbicides, and dates of herbicide application on the no-tillage establishment of alfalfa *(Medicago sativa* L.), birdsfoot trefoil *Lotus corniculatus* L.), and red clover *(Trifolium pratense* L.) in infertile grass swards in New England. The forage production of much of the permanent grassland in New England is limited by soil acidity, low fertility, and the botanical composition which persists under these soil conditions (Brown et al., 1960). Proper cutting or grazing management and fertililzation will improve botanical composition, but these practices require many years to achieve results (Milton, 1940). Forage production may be increased either by nitrogen fertilization or growing legumes. Since nitrogen fertilizer costs are rising, interest in forage legumes is increasing (Templeton, 1976).

Traditionally, poor-quality botanical composition is improved by planting desired forage species in seed-beds prepared by plowing and disking (Elliott and Squires, 1974). Tillage is costly in time,

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labor, equipment, fuel, and lost production (Frye et al., 1980). Moreover, there are many forage producing sites where tillage operations are limited by slope, stoniness, or other soil factors. The practices required for conventional seed-bed preparation have been identified as a major obstacle to the production of high quality forage in the humid region of the United States (Sprague et al., 1962a).

Renovation was the term which was originally used to describe the establishment of legumes in permanent grassland without plowing (Ahlgren et al., 1944). Four strategies have been developed: broadcasting seed at heavy rates on dormant sods, then reducing grass competition by burning and grazing (Graber, 1927); preparing a rough seed-bed by disking, then oversowing (Ahlgren et al., 1944; 1946; Sprague et al., 1947); applying broad-spectrum herbicides at rates sufficient to kill the perennial sod, then disking and oversowing (Sprague, 1952; Sprague et al., 1962a,b); and applying selective herbicides for sward suppression, then seeding directly into the sod with specially designed equipment (Decker et al., 1969; Taylor et al., 1969; Van Keuren and Triplett, 1972). The latter approach has been called no-tillage forage seeding. No-tillage in this sense means seeding without disturbance of the soil profile except for seed placement (Bauemer and Bakermans, 1973). No-tillage seeding can reduce energy expenditures for forage establishment by 32% when compared to standard practices for seed-bed preparation (Frye et al., 1980).

Proper seed placement and adequate moisture following seeding are critical factors for successful no-tillage legume establishment (Taylor et al., 1969). Liming and fertilizing are required for successful legume establishment in pastures (Odland et al., 1930). Since forage legume seeds are small, their nutrition reserves and capacities to survive environmental stress are limited (Cooper, 1977). The vulnerability of forage legumes to unfavorable growing conditions following seeding has made the selection of seeding dates an important factor in planning successful forage legume establishments (Fribourg and Strand, 1973). Herbicides may be used in legume seedings. Their role is expanded in no-tillage seedings because they replace tillage as a primary means of suppressing plant competition.

MATERIALS AND METHODS

Four experiments were conducted on swards with similar botanical compositions. Since common treatments were employed in the first three experiments, they were analyzed collectively. The fourth experiment continued investigation of certain effects of date of treatment on sward control which had been a major factor in the previous three experiments.

Experiments I, II, and III

Three interrelated field experiments were conducted at the Storrs Agricultural Experiment Station between October 1976 and August 1978. The soil was a Paxton very stony fine sandy loam (Typic Fragiochrept, coarse-loamy, mixed, mesic). Sand, silt, and clay fractions in the 0 to 12-cm horizon of this soil were 60, 33, and 7%, respectively. Soil samples taken before initiation of the experiments were pH 4.8 in 0.01 *M* $CaCl_2$ (Peech, 1965), and 336, 280, and 90 kg exchangeable K, Ca, and Mg/ha, respectively (McIntosh, 1969), and 22 kg/ha of extractable soil P (Bray and Kurtz, 1945).

Ground-cover estimates (Greig-Smith, 1964) before herbicide application were as follows: orchardgrass *(Dactylis glomerata* L.) 24%; quackgrass *(Agropyron repens* (Beauv.) L.) 21%; other grasses approximately 30%, including in order of prevalence: Kentucky bluegrass *(Poa pratensis* L.), bentgrasses *(Agrostis* sp.), timothy *(Phleum pratense* L.), and little bluestem *(Andropogon scoparius* Michx.); and perennial broadleaf weeds approximately 25%, including in order of prevalence: dandelion *(Taraxacum officinale* Weber.), buckhorn plantain *(Plantago lanceolata* L.), hawkweed *(Hieracium pratense* Tausch), red sorrel *(Rumex acetosella* L.), goldenrods *(Solidago* sp.), cinquefoils *(Potentilla* sp.), wild carrot *(Daucus carota* L.), blackberries *(Rubus sp.)*. and poison ivy *(Rhus radicans* L.).

In these three experiments, herbicide treatments were applied in October 1976, May 1977, and June 1977 (Table 1). Seedings which followed these herbicide treatments were made on 3 June 1977, following the October and May treatments, and on 19 July, following the July treatments. In each experiment the same legume species were seeded and the same liming treatments were applied. A combined analysis of variance was performed on all data (Cochran and Cox, 1957). Since the liming effects were not significant, the main and subplot error mean squares were pooled as a single error term. Experiments, species, herbicides, and their interactions were analyzed as a split-split plot design with three replications (Table 2). This analysis provides independent estimates of the effects of herbicide treatments within dates, specific chemicals, and the interaciton of specific chemicals with dates (Cochran and Cox, 1957).

Red clover (cv.'Pennscott'), alfalfa (cv.'Iroquois'), and birdsfoot trefoil (cv. 'Viking') were seeded at 9, 13, and 10 kg/ha, respectively. Lime was applied with all seedings at 4.5 mt/ha on 18 November 1976 or 19 May 1977 or as a split treatment wherein 2.2 mt/ha was applied on 19 May and an equal rate was banded through the Midland Zip Seeder at planting. Dry conditions followed 19 July 1977, the red clover seeding failed to emerge, and on 25 August 'Kenstar' red clover was seeded at 10 kg/ha in the plots previously seeded with red clover in July.

Except for the seeding of 'Kenstar', 98 kg P/ha was banded at planting. The June 1977 seedings received 93 and 139 kg K/ha on 25 May and 30 August 1977, respectively. The July 1977 seedings received 93 kg K/ha on 11 July 1977 and 11 April 1978. All plots were fertilized with 37, 139, and 2.5 kg/ha P, K, and B, respectively, on 26 June 1978.

The June seedings were harvested at the 5-cm height on 23 and 25 August 1977, 13 and 14 June, and 17 and 21 August 1978. The July 1977 seedings were harvested on 15 June and 22 August 1978. Botanical composition was assessed by visually estimating the percent weight of red clover, alfalfa, birdsfoot trefoil, orchardgrass, quackgrass, and each of the following groups of species: perennial grasses, perennial broadleaf weeds, annual grasses, and annual broadleaf weeds in the dry matter yield of all whole plots; then hand separating 1-kg samples and determining the dry matter percentages of introduced legumes and all other components for a randomly selected one-third of the plots. Correlation between the visual estimates and hand separations was highly significant for all legumes at all harvests ($P < 0.01$); therefore, dry matter yields of the seeded legume species were calculated as the product of the total forage dry matter yields multiplied by the visual estimate of the legume component.

Experiment IV

A fourth experiment was conducted between May 1978 and July 1979 on a Paxton very stony fine sandy loam of pH 5.8 on a northeast slope of 3 to 7%. Soil samples taken before seeding showed levels of K, Ca, and Mg of 248, 3160, and 514 kg exchangeable cations/ha and extractable soil P of 9 kg/ha. No lime or fertilizer was applied prior to seeding.

In May 1978, the ground cover of the sward was visually extimated as orchardgrass 30%; quackgrass 25%; Kentucky bluegrass 25%; perennial broadleaf weeds 15%: comprised chiefly of dandelion, Rugel's plantain *(Plantago rugelli* Dcne.), and white cockle *(Lynchis alba* Mill.); and birdsfoot trefoil 5%.

The experiment was conducted as a 3x2x2 factorial in a randomized, complete block design with four replications. The variables were dates of seeding, herbicide treatments, and types of rhizobial inocula. Iroquois alfalfa was seeded at 13 kg/ha with the Tye Pasture Pleaser Seeder on 2 June, 30 June, and 2 August 1978. The 2 June seeding emerged but failed to establish due to moisture stress and was reseeded on 30 June. Herbicide treatments were paraquat at 1.1 and glyphosate at 2.2 kg a.i./ha applied on 1 June, 29 June, and 31 July before their respective seedings. Herbicide treatments were reapplied on 29 June prior to the reseeding. The inocula were two commercial *Rhizobium mellilofi* strains, one prepared by Agway, Inc., and one by Nitragin, Inc. The Nitragin inoculum was amended with a water soluble adhesive. All plots were sprayed with carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methyl carbamate) at 1 kg a.i./ha on 16 June and fertilized with 139 kg K/ha on 6 September 1978.

Botanical composition was assessed on 1 June and 27 August 1978, and 1 June 1979, by visually estimating the ground cover of alfalfa, orchardgrass, quackgrass, Kentucky bluegrass, all perennial broadleaves, annual grasses, and annual broadleaves. All plots were harvested on 11 June and 24 July 1979, and dry matter yields determined. Random 1-kg botanical samples taken from all plots at the 11 June harvest were hand-separated into three categories: alfalfa, all grasses, and all broadleaves. Similarly obtained botanical samples taken from the 24 July harvest were hand-separated into alfalfa, all grasses, all volunteer legumes, and all other broadleaves. Dry matter yields of the botanical components were calculated by multiplying the total dry matter yields by the dry matter percentages determined in the hand-separated subsamples. Data from the fourth experiment were analyzed as a multiple, covariate matrix (Nichols et al., 1981).

RESULTS AND DISCUSSION

Experiments I, II, and III

In Southern New England, forage legumes may be seeded from spring through mid-summer. If the legumes are spring seeded, applying lime and herbicides the previous fall might facilitate lime penetration, sward control, and spring planting schedules. The combined analysis of variance indicated that legume yields were affected by dates of herbicide application and seeding for all harvests, and that the total forage yields were affected for the first two harvests ($P > 0.01$) (Table 2). The legume species and the interaction of seeded legume species with date of seeding and herbicide application affected legume yields for all harvests ($P > 0.01$). Total forage yields were affected by species in all harvests ($P > 0.01$). The interactions of species with dates were significant in the 1978 harvests ($P > 0.01$).

Herbicide performance is affected by environmental conditions and stage of plant growth (Aberg, 1964; Hammerton, 1967). When phytoselective chemicals are applied to mixed grass swards, the various component species are at different levels of physiological susceptibility. Some species are eliminated, others weakened, and some relatively unaffected by the herbicide treatment (Elliott, 1960; Allen, 1968). The surviving species will regrow and establish a new botanical equilibrium as influenced by plant growth habits and the degree to which the species had been weakened by the chemical (Elliott, 1960; Allen, 1968).

Herbicide treatments, specific chemicals, and the interaction of specific chemicals with dates affected legume yields at all three harvests and the total forage yields in August of 1977 and 1978 ($P < 0.01$) (Table 2). June forage yields were comprised largely of the accumulated spring growth of the cool-season, perennial grasses which produced their principal seasonal growth in April and May. Forage legumes are expected to produce a greater proportion in suceeding summer harvests. The inclusion of forage legumes provides a more uniform distribution of production in cool-season grass forage production systems (Hamilton et al., 1969).

The highly significant herbicide x date interaction indicates that the same chemicals applied on different dates produced different effects on legume establishment ($P > 0.01$). Moreover, the interaction of seeded legume species with herbicide treatments, different chemicals, and the same chemicals applied on different dates, affected legume yields in 1978 ($P > 0.01$). The significance of these effects on legume yields shows that different forage legume species require different levels of sward control for effective establishment in perennial grass swards. Not only did different herbicides produce different levels of control, the same herbicide applied on different dates produced different levels of control and the legumes responded differently.

The herbicides amitrole, dalapon, glyphosate, and paraquat differed in their effects on an orchardgrass-quackgrass sward when applied in October, May or July (Table 3). In addition, the legumes responded differently to growing conditions when seeded in early June or mid-July. The factors of sward control and legume growth interacted to produce legume stands which differed in legume and overall forage production in the first and second years (Figure 1).

No-tillage establishment of a forage legume on an acid soil depends on the tolerance of the seeded species to moisture stress, soil reaction, and plant competition. Alfalfa and red clover have been classified as very competitive forage species, while birdsfoot trefoil has been described as a poor competitor (Blaser et al., 1956). Birdsfoot trefoil is the most acid tolerant of these three legumes (Seaney and Henson, 1970); red clover tolerates moderately acid soils, but grows best on soils above pH 6.0 (Taylor, 1973). The growth of alfalfa is greatly reduced by soil acidity (Munns, 1965). Overall, on a soil of pH 4.8, red clover, birdsfoot trefoil, and alfalfa established most, intermediately, and least readily, respectively.

Adequate soil moisture was available in June 1977. All legume establishments were limited by lack of soil moisture in July and August 1977. The June seedings of red clover established well. The July red clover seeding failed to emerge and the August reseeding produced the least productive red clover stands of these three experiments. Alfalfa stands from the July seedings were fair and those of birdsfoot trefoil were fair to poor. Based on these observations, the alfalfa evidenced the most, birdsfoot trefoil intermediate, and red clover the least tolerance to dry conditions following seeding.

Birdsfoot trefoil established slowly but steadily over a broad range of conditions and stands increased in vigor in 1978. Red clover established readily with all herbicide treatments when soil moisture was not limiting, but stands declined in 1978. Short stand life has been a continuing problem with red clover cultivars (Cressman, 1967).

In Experiments I, II, and III, the botanical composition of a harvest depended on the herbicide treatment, the date of herbicide application, the legume species seeded, the degree to which the legume established, and the interval between the harvest, the herbicide application, and the no-tillage seeding. Both pronamide and dalapon substantially reduced the ground cover of the perennial grasses. Since by August 1977, nine months had elapsed since the

October herbicide treatments and two months since those applied in May, the October sprayed perennial grasses had recovered from treatment to a greater extent than those sprayed with the same treatments in May (Table 3). Neither dalapon nor pronamide controlled the perennial broadleaf species which regrew vigorously when released from competition with the grasses (Table 3). Dandelion infestations have increased in established alfalfa stands following application of pronamide for quackgrass control (Triplett et al., 1977).

Amitrole applied in May or July successfully controlled many difficult to control sward species including quackgrass, poison ivy, and blackberries. Bentgrass *(Agrostis stolonifera* L.) was the principal species which survived and colonized open spaces following amitrole treatment. In August of the second year, the yields of perennial broadleaf weeds were lower in the May or July amitrole treated plots than in any except those treated in July with glyphosate or the split application of paraquat ($P < 0.05$) (Table 3). Amitrole residues also caused stand losses of approximately 30% to the red clover, 60% to the birdsfoot trefoil, and 90% to the alfalfa seedlings, following a 21-day interval between spraying and seeding in May and July.

October applied paraquat or glyphosate did not control the sward's May regrowth. May applied paraquat rapidly dessicated the sward and reduced the ground cover of Kentucky bluegrass *(Poa pratensis* L.) in the regrowth. Orchardgrass, many perennial broadleaf weeds, and quackgrass regrew vigorously following this treatment. The ground cover of quackgrass was increased by May applied paraquat. Although May applied glyphosate suppressed all the sward species, orchardgrass and quackgrass were not eliminated. Following the May glyphosate application, many volunteer weeds, chiefly crabgrass *(Digitaria* sp.), yellow foxtail *(Setaria glauca* (L.) Beauv.), buckhorn plantain, ragweed *(Ambrosia artemisifolia* L.) and red sorrel emerged and established in the open spaces left by the control of the susceptible perennials. Higher yields of annual weeds were obtained in August 1977 from the May applied glyphosate treatment than from the other treatments ($P < 0.05$) (Table 3). Lower yields of perennial grasses were obtained from the May applied glyphosate treatment in August 1977 than from any treatment except May applied dalapon ($P < 0.05$) (Table 3). Similar invasions of weeds occur when residual chemical control is Inot used in conventional forage seedings.

Glyphosate was as effective for perennial sward control when applied in July as in May and the invasion of volunteer weeds was less for July. Emergence of annual weeds is less in July and August compared with May and June (Stoller and Wax, 1973). The regrowth of the perennial grasses was slower following the July application of paraquat at 1.1 kg a.i./ha than following the May application. This slower recovery was consistent with the annual growth cycle of cool-season, perennial grasses and their response to higher temperatures and evapotranspiration potentials (Baker and Jung, 1968a,b). The split application of paraquat was more effective for controlling the perennial grasses than the single 1.1 kg a.i./ha treatment but was less effective than glyphosate at 2.2 kg a.i./ha applied in either May or July.

Paraquat and glyphosate gave different levels of control when applied in May, July, and October. In May these perennial grasses are beginning maximum annual growth; in July they are beginning midsummer semi-dormancy; and in October they approach winter dormancy. Paraquat is primarily a contact herbicide whose effect is similar to defoliation. The response of the sward to paraquat applied in May, July, and October was consistent with the anticipated response of cool-season grasses to defoliation on these dates. Summer applications of paraquat to mixed grass swards have been more effective than fall applications (Oswald, 1972).

Glyphosate is a systemic herbicide which induces phytotoxicity only when physiological conditions permit uptake and translocation (Spankle et al., 1975). Since environmental conditions vary for dates among years, plant susceptibility also varies. Different dates of maximum glyphosate activity on cool-season grass swards have been reported (Peters and Lowance, 1974; Oswald, 1976). Significantly different yields of perennial grasses were obtained in June 1978, following the same rate of glyphosate applied in May, July, and October of the previous year ($P < 0.05$) (Table 3).

Quackgrass was the perennial grass least affected by the paraquat, dalapon, or glyphosate treatments. Translocation of glyphosate into quackgrass rhizomes is reduced at soil temperature of 10° or 30° versus 21°C (Majek, 1980). Soil tempeature has a greater effect on glyphosate translocation to quackgrass rhizomes than air temperature or photoperiod (Majek, 1980). In May and July, temperatures were moderate, soil moisture was adequate, and more than 90% sod suppression was obtained two weeks following the glyhphosate treatment. During the 10 days preceding and following the October glyphosate treatment, the daily maximum air temperature was as high as 10°C only once and phytotoxic symptoms were not observed in the sward species.

Red clover established well following all October and May applied herbicides (Table 4). Birdsfoot trefoil and alfalfa established best following May applied glyphosate. Satisfactory birdsfoot trefoil stands were established with October or July applied paraquat or glyphosate. Satisfactory alfalfa stands established following paraquat applied in May, or July applications of glyphosate or a split application of paraquat.

All liming treatments provided 4.5 mt/ha lime. For a conventional legume seeding, all or part of the lime would be plowed-down. In no-tillage, all soil amendments must be broadcast. In Connecticut, the rate of penetration of lime is more dependent on time elapsed since application than on the rate applied (Brown et al., 1956). The rate of penetration of lime on a Paxton fine sandy loam of initial pH 5.2 was found to be 2 cm/yr independent of liming rate between 2 and 18 mt/ha (Brown et al., 1956).

Fall liming or banding lime in the immediate vicinity of the seed might stimulate seedling growth and enhance nodulation. However, no effects of the liming treatments were observed on the yields of any of the seeded legumes ($P < 0.05$). Fall liming increased the growth of the perennial grasses in June 1978 ($P < 0.01$) and may have offset positive effects on legume growth by increasing competition from the sward. The yields of the perennial grasses following the fall, spring, and banded lime treatments were 1.16, 0.90, and 0.90 mt/ha in June 1978 averaged over all other variables ($n = 108$).

Experiment IV

Plots which were sprayed on 1 June 1978 were resprayed on 29 June because the alfalfa seeding failed due to moisture stress and was reseeded concurrently with the plots allotted for the second date of seeding. Ground cover of annual weeds in the doubly sprayed 1 and 29 June treated plots and those sprayed only on 29 June did not differ ($P < 0.05$) (Table 5). Plots sprayed only on 31 July had much less ground cover of annual weeds than those sprayed earlier ($P < 0.05$). The principal annual weeds which emerged on this site were large crabgrass *(Digitaria sanguinalis* (L.) Scop.), green foxtail *(Setaria viridis* (L.) Beauv.), common lambsquarters *(Chenopodium album* L.), redroot pigweed *(Amaranthus retroflexus* L.) and Pennsylvania smartweed *(Polygonum pensylvanicum* L.).

In Experiments I, II, and III seeded in 1977 and in Experiment IV seeded in 1978, greater germination of annual weeds occurred following disturbance of the sward with herbicides in May or June versus July. Mid-summer seeding of alfalfa is recommended in Connecticut because the emergence of annual weeds is less in July and August compared with earlier in the season.

The double herbicide application reduced the orchardgrass and increased the quackgrass ground cover as compared to the single applications ($P < 0.05$) (Table 5). Perennial grass yields on 11 June were highest following the July 1978 applied herbicides ($P < 0.05$).

Perennial broadleaf weed yields were highest following the earliest date of herbicide application ($P < 0.05$). Trends in perennial grass and perennial broadleaf weed yields in Experiments I, II, and III and in Experiment IV were consistent among dates of application considered collectively over a set of herbicides differing widely in their modes of action and species selectivity. May and June treatments produced the most damage to the perennial grasses. This was reflected in increased cover of annual weeds in the seeding year and decreased grass yields and increased yields of perennial broadleaf weeds in the second year. Since a no-tillage legume seeding on an acid soil will probably result in a grass-legume mixture, it would be advantageous to maintain a maximum cover of desirable forage grasses and a minimum cover of perennial broadleaf weeds, consistent with the successful establishment of a legume stand. This botanical composition was more frequently obtained by late season disturbance of the sward.

Alfalfa yields were higher with glyphosate than paraquat treatments ($P < 0.05$) (Table 6). Perennial grass yields were higher on 11 June following paraquat than with glyphosate ($P < 0.01$). Perennial broadleaf yields were higher in the glyphosate treated plots ($P < 0.01$). Both paraquat and glyphosate, followed by the alfalfa seeding, reduced the ground cover of Kentucky bluegrass from near 30% in June 1978 to less than 10% in June 1979 (Figure 2). Glyphosate reduced the ground cover of orchardgrass compared to paraquat ($P < 0.05$). In August of the seeding year, glyphosate reduced the ground cover of perennial broadleaf weeds and quackgrass but a higher ground cover of perennial broadleaf weeds was observed in the glyphosate plots in 1979. No differences were observed in quackgrass ground cover in 1979 ($P < 0.05$).

Kentucky bluegrass, orchardgrass, and quackgrass are controlled by paraquat and glyphosate in that order of facility (Figure 2). Paraquat is sufficient to control Kentucky bluegrass but has not proven sufficient to control orchardgrass in New England. Although glyphosate is generally sufficient to control Kentucky bluegrass and orchardgrass, quackgrass is more difficult to control. Quackgrass will generally increase in prevalence following the application of paraquat to a mixed grass sward and often increases the year following glyphosate. Since glyphosate controls the perennial grasses, open spaces are left in the sward. These spaces may be occupied by legume seedlings, annual weeds, or the seedlings of broadleaf perennial weeds (Table 6). Disturbance of the sward sufficient for legume introduction is also sufficient for the establishment of weeds.

The emergence of chlorotic alfalfa seedlings from no-tillage seedings has been observed (West et al., 1980). Early, effective noduiation might accelerate legume seedling growth and confer an advantage on the legume. Adhesive amendments that promote seed-*Rhizobium* contact have increased the establishment of subterranean clover *(Trifolium subterranean* L.) (Jones et al., 1978).

Weed-free alfalfa yields were increased by the use of an adhesive-amended- compared with a dry-rhizobial inoculum ($P < 0.01$) (Table 6). Whereas total forage yields were not influenced by herbicide or date effects ($P < 0.05$), use of the adhesive-amended inoculum increased total forage yields for the sum of two harvests from 4.17 to 4.81 mt/ha ($P < 0.01$). The conclusion that the use of an adhesive amendment with the *Rhizobium* increased establishment of no-tillage seeded alfalfa is tentative, since it is drawn from one year's observation.

Factors Limiting Legume Establishment

Proper seed placement and coverage are critical for a successful no-tillage forage legume seeding (Taylor et al., 1969; Swain, 1976). The small legume seed must be planted shallow enough to permit the cotyledons to emerge but deep enough to provide soil coverage for a microenvironment conducive to germination, root development, and seedling survival during stress (Cooper, 1977). Frequently, within-row skips in the seedings made on experiment plots can be attributed to soil roughness or surface trash which prohibits proper seed placement or adequate coverage of the seed.

Sufficient soil moisture during the period of seedling establishment is essential to produce a uniform stand (McWilliams et al., 1970). The critical moisture levels and the duration of the critical period depend on the soil, the legume species seeded, the rate of accumulation of the evapotranspiration deficit, the rate of seedling root development, and the intensity of plant competition. In the experiment here reported, the interval between the cotyledon stage and development of the third true-trifoliate leaf was most critical for stand establishment. Large decreases in seedling populations often occurred during this interval due to environmental conditions, plant competition, or phytophagous insects.

Soil reaction and fertility levels must be within the ranges required for rapid growth of the seeded legume. The failure of alfalfa, a competitive forage species, to rapidly establish on a soil of pH 4.8 illustrates this requirement (Blaser et al., 1956). Soil acidity is a major factor restricting the survival of rhizobia in soils (Rice et al., 1977). Early, effective nodulation will increase the probability of legume seedling establishment (Vincent and Waters, 1954). The use of adhesive amendments has been suggested as a means of improving the efficiency of legume seed inoculation (Vincent, 1965). The alfalfa nodulating bacteria, *Rhizobium melliloti,* is the least tolerant of acidity of all *Rhizobium sp* (Graham and Parker, 1964). No-tillage establishment of alfalfa on strongly acid soils may be limited until rapid, effective means of neutralizing soil acidity in the legume rhizosphere are developed.

Sward and annual weed control must be sufficient for legume seedling establishment. Yields of summer annual forages and small grains seeded in partially killed sods are directly proportional to the percent of sod killed (Sprague et al., 1962b). Although the number of seedlings which emerge is not affected by the degree of sward control, differences in growth are observed ten days following seedling emergence (Sprague et al., 1962b).

Selection of a program for sward and weed control must begin with an assessment of the botanical composition of the sod. Herbicides differ in their selectivities among the grasses and weeds which comprise mixed, perennial swards (Allen, 1968; Triplett et al., 1975; Oswald, 1976). Moreover, the relative susceptibilities of the sward species vary with the date of treatment and environmental conditions (Allen, 1965; Peters and Lowance, 1974).

No-tillage Legume Establishment: Strategies for New England

An overall plan for a no-tillage legume seeding must account for the rate of growth of the legume species, the botanical composition of the sward which must be controlled, and the date of seeding which will maximize conditions favorable for the growth of the seeded legume, enhance the susceptibility of the resident species to control, and minimize the subsequent invasion of annual weeds.

On a soil of pH 4.8, red clover established more readily by no-tillage than did birdsfoot trefoil which established more readily than did alfalfa. In a separate experiment on a soil of pH 5.8, a no-tillage seeding of alfalfa established well. Fall compared to spring liming did not benefit legume establishment. Fall liming of an acid soil may increase sod competition which counteracts the otherwise beneficial effect of lime on legume growth.

Red clover established readily over a wide range of plant competition but stands were productive for only two years. Alfalfa stands established by no-tillage developed more slowly than would be expected of conventionally seeded alfalfa. Alfalfa plants developed in vigor and yields improved in the second year. Birdsfoot trefoil was intermediate between red clover and alfalfa in its ease of establishment. Birdsfoot trefoil stands developed slowly but steadily following their initial establishment. Alfalfa was least, birdsfoot trefoil intermediate, and red clover most sensitive to moisture stress in the seedling stage. Early June seedings were superior to mid-July seedings in 1977. July seedings were superior to early June seedings in 1978. The distribution of rainfall varies between years.

Pronamide and dalapon lacked activity against broadleaf perennial weeds and did not provide sufficient control for establishment of alfalfa or birdsfoot trefoil. Amitrole residues were very phytotoxic to alfalfa and birdsfoot trefoil and moderately phytotoxic to red clover. Amitrole controlled several difficult to control sward species. High yields of red clover and birdsfoot trefoil were harvested the second year following amitrole application. Paraquat was most effective when applied in July, especially as a split application. Summer applications of paraquat take advantage of the midsummer lag in cool season, perennial grass growth. Spring applications of paraquat coincide with the period of maximum seasonal growth of the cool season grasses. Glyphosate, a systemic broad spectrum herbicide, was effective for overall sward control and no-tillage establishment of alfalfa and birdsfoot trefoil. Glyphosate was ineffective when applied in cool weather on 30 October 1976. Glyphosate has been effective for weed control when applied in October during warmer conditions (Peters, unpublished). May, June, and July applications of glyphosate provided excellent control for three to four weeks. May or early June glyphosate applications were followed by severe infestations of volunteer weeds. Invasions of annual weeds were reduced where glyphosate was applied later in the season.

The best strategy for red clover establishment was an early season seeding. Red clover establishment does not require radical disturbance of the sward. The best strategy for alfalfa or birdsfoot trefoil establishment required glyphosate applied in summer when the emergence of volunteer weeds is less.

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Table 1. Herbicide treatments and dates of application.

Dates of Application					
30 October 1976		12 May 1977		11 July 1977	
Herbicides and Rates[1]					
paraquat	1.1	paraquat	1.1	paraquat	1.1
glyphosate	2.2	glyphosate	2.2	glyphosate	2.2
dalapon	16.8	dalapon	16.8	amitrole	4.5
pronamide	2.2	amitrole	4.5	paraquat[b]	0.5 plus 0.5

[1]All rates are in kg a.i./ha.

[2]Paraquat was applied as a split application of 0.5 kg a.i./ha on 11 July plus 0.5 kg a.i./ha on 18 July.

Table 2. Analysis of variance of legume and total forage yields on three dates as affected by dates of herbicide application and no-tillage seedings, species, and herbicide treatments.

Sources of† Variation	df 1977	df 1978	Legumes Alone Aug. 77	Legumes Alone June 78	Legumes Alone Aug. 78	Total Forage Aug. 77	Total Forage June 78	Total Forage Aug. 78
			mean squares					
Dates	1	2	3.3203**	37.3786**	14.4044**	14.3067**	23.9090**	4.6850
error a	16	24	0.1375	0.4748	0.2172	0.8459	2.1658	1.7100
Species	2	2	13.1714**	85.6559**	12.9728**	7.4059**	6.0797**	20.9946**
Sp. x Dates	2	4	0.2820*	16.7777**	3.9349**	0.4244	4.7571**	2.8703**
error b	32	48	0.0738	0.2641	0.4598	0.1863	0.5063	0.4241
Herb. (Dates)	6	9	1.0249**	2.1045**	2.4709**	3.4374**	0.5843	1.2560**
Herb.	4	5	0.8380**	2.7836**	2.5777**	3.9216**	0.6726	1.3941**
Herb. x Dates	2	4	1.3988**	1.2556**	2.3374**	2.4689**	0.4738	1.0833**
Sp. x Herb. (Dates	12	18	0.0608	0.9975**	0.7819**	0.2969	0.6041*	0.4765**
Sp. x Herb.	8	10	0.0467	1.0450**	0.8818**	0.1128	0.7300*	0.3349
Sp. x Herb. x Dates	4	8	0.0889	0.9382**	0.6570**	0.6652*	0.4468	0.6536**
error c	144	216	0.0443	0.1956	0.2191	0.2590	0.3713	0.2217

†Sp. and Herb. denote seeded legume species and herbicide treatments, respectively.
*, ** denote significant F values at P = 0.05 and P = 0.01, respectively.

Table 3. Effects of herbicides and dates of application on yields of botanical components in selected harvests.

Herbicide[1] Treatments	Rates	Perennial Grasses		Annual Weeds	Prennial Broadleaf Weeds	
		Aug. ‡‡[2]	June 78	Aug. 77	Aug. 77	Aug. 78
	kg a.i./ha	mt/ha				
October 1976						
glyphosate	2.2	0.45 b[3]	0.90 d	0.13 bc	0.18 c	0.25 a
paraquat	1.1	0.44 b	1.08 cd	0.06 c	0.23 b	0.23 a
dalapon	16.8	0.45 b	0.72 de	0.21 b	0.32 a	0.26 a
pronamide	2.2	0.35 c	1.19 bc	0.26 b	0.29 a	0.20 ab
May 1977						
glyphosate	2.2	0.07 d	0.53 e	0.90 a	0.09 d	0.18 b
paraquat	1.1	0.40 bc	0.93 d	0.08 c	0.16 c	0.16 bc
dalapon	16.8	0.14 d	0.59 e	0.18 bc	0.30 a	0.18 b
amitrole	4.5	0.61 a	0.77 de	0.06 c	0.12 cd	0.06 d
July 1977						
glyphosate	2.2	—[4]	1.10 c	---[4]	---[4]	0.09 cd
paraquat	1.1	----	1.34 ab	----	----	0.09 cd
paraquat	0.5 + 0.5	----	1.07 cd	----	----	0.12 c
amitrole	4.5	----	1.57 a	----	----	0.04 d

[1]Subheadings specify dates of herbicide application; seedings following the October and May or July herbicides were made on 3 June or 19 July 1977, respectively.

[2]Dates of harvests.

[3]Harvest means, within species, and dates of herbicide application, followed by the same letter do not differ significantly at the 5% level as determined by Duncan's Multiple Range Test.

[4]No harvest taken.

Table 4. Dry matter yields of the legume components on three dates as influenced by dates of herbicide application and seedings, legume species, and herbicide treatments.

Herbicide[1] Treatments	Rates	Red Clover			Birdsfoot Trefoil			Alfalfa		
		Aug. 77[2]	June 78	Aug. 78	Aug.77	June 77	Aug. 78	Aug. 77	June 78	Aug. 78
	kg a.i./ha	mt/ha								
October 1976										
glyphosate	2.2	1.46 ns[3]	3.35 a	1.24 ns	0.94 ns	1.18 a	0.94 b	0.02 ns	0.26 ns	0.36 ns
paraquat	1.1	1.29 ns	3.35 a	1.11 ns	0.84 ns	1.30 a	1.49 a	0.02 ns	0.47 ns	0.38 ns
dalapon	16.8	1.68 ns	3.60 a	1.48 ns	1.45 ns	0.68 b	0.79 b	0.02 ns	0.22 ns	0.24 ns
pronamide	2.2	1.68 ns	2.62 b	1.08 ns	1.21 ns	0.72 b	0.73 b	0.02 ns	0.32 ns	0.37 ns
May 1977										
glyphosate	2.2	2.14 a	2.80 bc	1.35 ab	2.22 a	2.15 a	2.08 a	1.16 a	2.15 a	2.28 a
paraquat	1.1	1.86 ab	3.19 ab	1.55 ab	0.94 b	1.65 b	1.97 a	0.15 b	1.12 b	1.42 b
dalapon	16.8	1.52 bc	2.59 c	1.13 b	0.92 b	1.45 b	.1.20 b	0.12 b	0.58 c	0.88 c
amitrole	4.5	1.20 c	3.44 a	1.76 a	0.66 b	1.58 b	2.14 a	0.09 b	0.66 c	0.93 c
July 1977										
glyphosate	2.2	—[4]	1.15 ns	2.30 a	—	1.25 a	1.65 a	—	0.92 a	1.33 a
paraquat	1.1	—	1.05 ns	1.40 b	—	0.51 b	1.01 b	—	0.46 bc	0.71 bc
paraquat	0.5 + 0.5	—	0.82 ns	2.27 a	—	1.13 a	1.51 a	—	0.64 ab	1.02 ab
amitrole	4.5	—	0.80 ns	1.91 ab	—	0.32 b	0.65 b	—	0.28 c	0.56 c

[1]Subheadings specify dates of herbicide application; seedings following the October and May or July herbicides were made on 3 June or 19 July 1977, respectively.

[2]Dates of harvests.

[3]Harvest means, within species, and dates of herbicide application, followed by the same letter do not differ significantly at the 5% level as determined by Duncan's Multiple Range Test.

[4]No harvest taken.

Table 5. Ground cover and yields of selected botanical components in Experiment IV in 1978 and 1979.

Date of Herbicide Application	Date of Observation or Harvest				
	27 August 1978	1 June 1979		11 June 1979	
	Annual Weeds	Orchardgrass	Quackgrass	Perennial Grasses	Broadleaf Weeds
	% ground cover			mt/ha	
1 & 29 June 1978	51.6 a[1]	16.5 b	21.9 a	1.36 b	0.64 a
29 June 1978	43.2 a	31:7 a	13.6 b	1.60 b	0.39 b
31 July 1978	1.3 b	29.5 a	13.9 b	1.91 a	0.39 b

[1]Means within columns followed by the same letter do not differ significantly at the 5% level as determined by Duncan's Multiple Range Test (DMRT).

Table 6. Effects of herbicides on yield components of Experiment IV in 1979.

Herbicides	11 June 1979[1]			24 July 1979[1]	
	Alfalfa	Perennial grasses	Perennial broadleaves	Alfalfa	Perennial broadleaves
	mt/ha				
glyphosate	1.04*	1.35	0.60**	0.82**	0.19*
paraquat	0.84	1.87**	0.35	0.10	0.10

[1]Dates of harvests.

*, **, significant according to the factorial analysis of variance at the 5 and 1% levels, respectively.

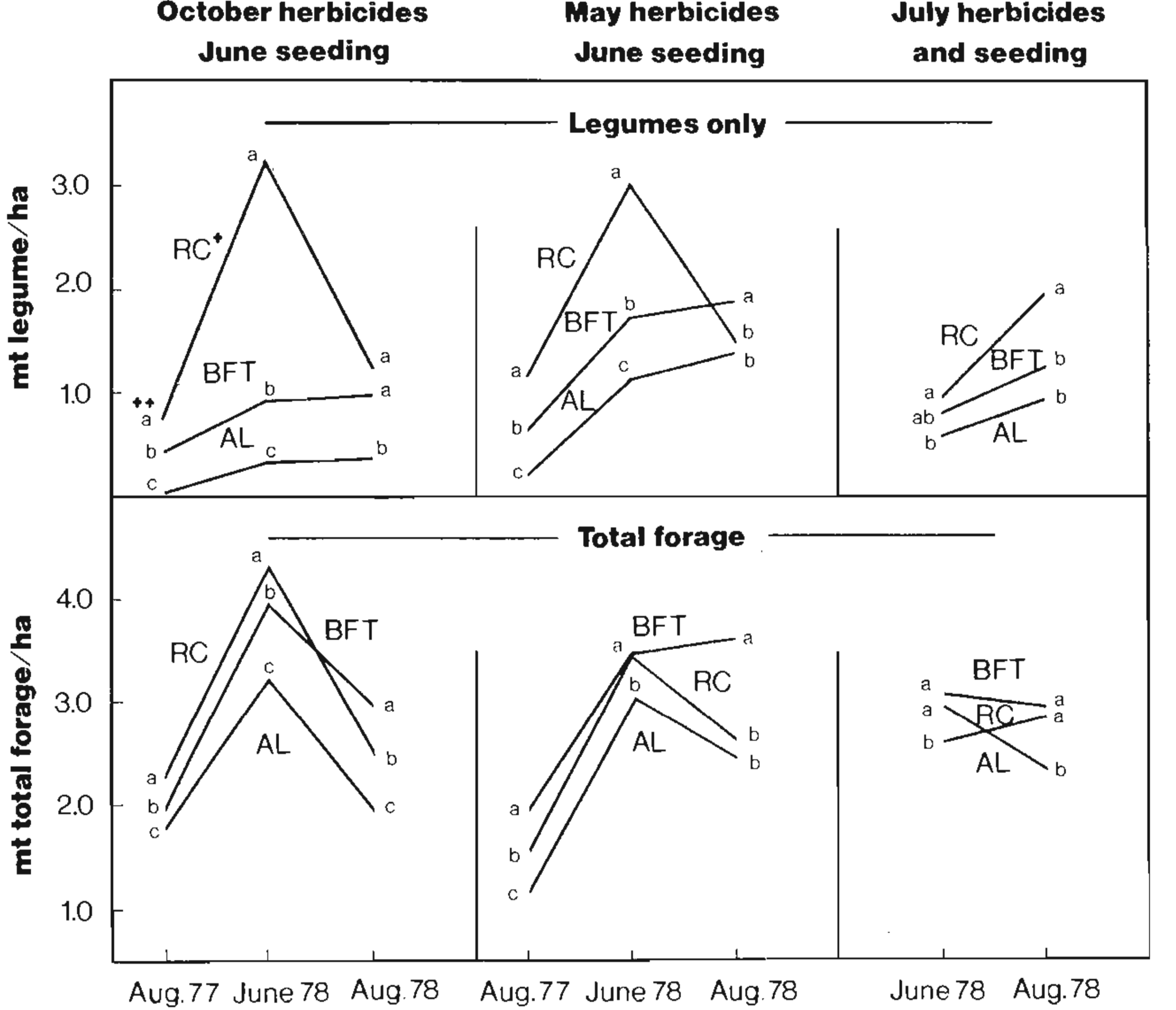

Figure 1. Experiments I, II, and III; Effects of May, July and October Applied Herbicides on Yields of the Legume Components and Total Forage.

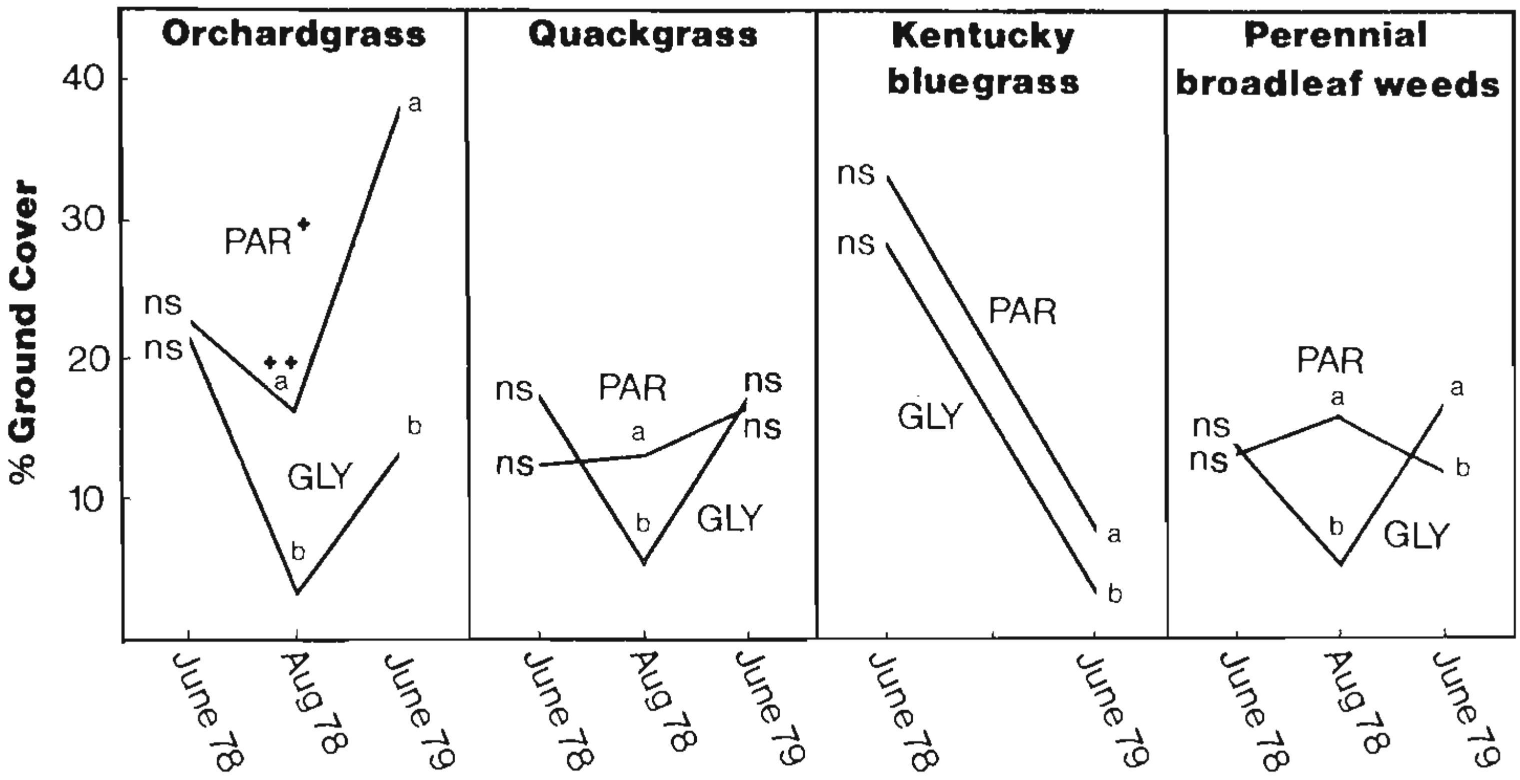

Figure 2. Experiment IV; Effects of Paraquat and Glyphosate on Ground Cover of Perennial Grasses and Broadleaf Weeds in a Mixed Sward.