Comparison of tillage and herbicide treatments for alfalfa renovation
by John Arlington Hall

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

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Experiments were established at three locations in 1981. Herbicide and tillage treatments were applied in a split plot, randomized complete block design. Subplots consisted of treatment in: (1) one year only, (2) two consecutive years, and (3) three consecutive years.

Tillage reduced alfalfa stand densities but yields were not greatly affected by stand reductions. Deep (10 cm) tillage with a shank implement benefited alfalfa lacking vigorous growth. Both percentage of alfalfa in forage and total forage yield were increased. Chemical treatments improved the percentage of alfalfa in forage but not forage yield. Deep tillage did not improve yields in young, dense, vigorous alfalfa stands. Tillage increased soil temperature, and plant tissue analysis indicated an increased uptake of N and P by alfalfa in tilled plots.

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ABSTRACT

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CHAPTER I

INTRODUCTION

Weeds invading aging alfalfa (*Medicago sativa* L.) stands compete with alfalfa and reduce alfalfa yield. Some growers are attempting to renovate alfalfa by intensive spring tillage.

Tillage of alfalfa stands is practiced in many areas of Montana (especially Western Montana). Some alfalfa growers are tilling young stands and are including deep tillage as an annual management practice. Implement dealers are selling narrow shanks called "alfalfa points" and are encouraging this practice.

Agronomists have received many questions concerning tillage of alfalfa fields. Therefore, research was initiated in 1981 by the Montana Agricultural Experiment Station to: (1) determine short and long term effects of various tillage operations on weed control, yield, plant density, and longevity of forage stands, (2) evaluate several labeled, dormant applied herbicides for weed control and productivity of alfalfa, (3) compare the effects of tillage versus herbicides, and (4) determine the effects of various levels of tillage on young vigorously growing alfalfa.

CHAPTER II

LITERATURE REVIEW

Alfalfa (*Medicago sativa* L.), the most widely grown hay crop in the world, has been extensively researched and improved for over one hundred years. Germplasm exploration beginning in the late nineteenth century and subsequent cultivar development have increased use and distribution of alfalfa in the U.S. (59). Management practices are continually being altered to better suit new germplasms and differing environments of various regions.

Tilling established alfalfa is an old management tool, developed and promoted as a weed control measure (1,4,13,18,55,62,69). Since the introduction of selective herbicides in the mid-1950s, tillage has decreased in popularity, but is still practiced by many alfalfa growers.

Direct Effects of Tilling in Established Alfalfa Stands

Weed Competition

A weed is "any plant growing where it is not wanted" (55). Annual and perennial grasses and broadleaved weeds are common weed problems in aging alfalfa fields (4,62). Since most weeds invading alfalfa fields have shallower root systems than alfalfa, tillage has been used to reduce weed competition.

New alfalfa stands are susceptible to weed infestations. Most weeds, however, do not flourish in mature, dense, vigorously growing alfalfa (18,55). Failure to control weeds in the establishment year may result in poorly competitive stands (18,69). When alfalfa stands become thin, sunlight reaching the soil surface stimulates weed seeds to germinate (55).

Winter annuals that germinate and grow while the alfalfa is dormant can invade even vigorous stands of alfalfa (6,62). Weeds reduce alfalfa yields through competition for water, nutrients and light. Weeds also reduce the quality of harvested forage (55).

Degree of competition between grass and alfalfa depends on the grass species. Stand density ratings (space occupied by alfalfa plants) of numerous alfalfa cultivars increased in each of four years following seeding when grown with intermediate wheatgrass (*Agropyron intermedium* [L.] Beauv.) or crested wheatgrass (*Agropyron cristatum* [L.] Beauv.) (30). However, alfalfa stand density ratings declined when alfalfa was planted in mixtures with Russian wild ryegrass (*Elymus junceus* Fish.) or smooth bromegrass (*Bromus inermis* Leyss.) (32). Grass competition is greatest in early spring as growth commences from the crown buds of alfalfa (8,23). Vigorously growing alfalfa is equally competitive with grasses for moisture and nutrients in the upper 30 cm of the soil profile (3).

Tillage Studies

The value of tilling established alfalfa has often been questioned. Experiments in Colorado during the 1930s indicated that cultivation of alfalfa had little effect on either weed populations or alfalfa plants (69).

At Prosser, Washington in 1938, a disk, spring-tooth harrow, and Hankmo renovator (spiked teeth on a revolving shaft) were used in various combinations of early spring and late fall tillage to control downy bromegrass (*Bromus tectorum* L.) (62). Results were erratic because of variation in the initial downy brome and alfalfa populations, but indicated a marked reduction in downy brome by all tillage treatments. Treatments incorporating both early spring and late fall tillage were most effective in controlling downy brome, but reduced alfalfa yields slightly. A single spring tillage did not affect alfalfa yields.

Similar results were reported by Bruns et al. (4) twenty years later in Washington. They noted that downy brome control was short lived, and concluded that tillage caused considerable damage to alfalfa crowns.

Garver (18) summarized alfalfa cultivation experiments conducted in South Dakota during the 1930s. Alfalfa cultivated with a spring-tooth harrow each spring for five years had higher stand density ratings (space occupied by alfalfa plants), and yielded similar to noncultivated alfalfa. Disking improved alfalfa yields for two years and then decreased both stand density and yield in the remaining years. All cultivation treatments reduced weed populations.

Alfalfa growth is initially slowed by tillage, however, normal growth soon resumes with no permanent adverse effects to the alfalfa plant (13). Delayed growth may result from crown bud injury (55). Implements with straight chisel-type teeth normally slide around well rooted alfalfa plants causing minimum damage to the roots (13,55,62). In contrast, deep set disks can cause extensive damage to alfalfa crowns and roots (13).

Dawson and Timmons (13) advocated frequent spring tillage of alfalfa seed fields "until the field looks as if it had been plowed and harrowed to form a seedbed." This created a dust mulch at least 5 cm deep which provided excellent weed control with no apparent adverse effects on the alfalfa.

Leyshon (41) investigated using a power seeder to drill fertilizer (P_2O_5) between wide-spaced (45-90 cm) alfalfa rows. Yields were not increased by banding fertilizer 2.5 cm deep and were decreased when the fertilizer was placed 10 cm deep. He concluded that alfalfa root damage was responsible for the yield reduction. A second study, where soil between alfalfa rows was tilled to 10 cm without the addition of fertilizer, supported his earlier conclusion (41).

Pesak (54) found that drilling P_2O_5 into legume-grass meadows decreased forage yields the first harvest following treatment, but yields recovered in subsequent harvests and years.

Stand Density

Although tillage will probably reduce alfalfa plant density (plants per unit area), its effects on plant size and tillering capacity are not well known. Alfalfa adjusts its growth habit to the surrounding environment. Rapid tillering commonly occurs in sparse stands (5,11,50), especially when carbohydrate root reserves are high (11,23). Tiller number of healthy alfalfa plants may vary from five to thirty stems per crown (5,11).

Soil moisture, light intensity, temperature, mineral nutrition, disease, and cutting frequency affect tillering capacity and plant vigor (11,39). Carbohydrate production and accumulation is the major determinant for crown bud initiation and development (11,23).

Increases in crown diameter the year following seeding normally increases stand density (space occupied) even though plant numbers are reduced (18,29,36,68). Competition for space, nutrients and water among seedlings in dense stands reduces plant vigor. Larger plants usually persist and thrive while smaller ones die (39).

Kehr et al. (29) stated that tap root size is determined more by stand density (plants per unit area) than by cultivar characteristics. Tap roots commonly increase in diameter as space becomes available (29,36).

Kehr et al. (29) and Kramer et al. (36) reported that stand densities based on plants per unit area do not account for the tremendous variation in crown size and plant vigor in a field; therefore, plants per unit area is not often highly correlated with yield. Plant numbers in excess of those needed to obtain maximum leaf area index do not necessarily contribute to greater yields (29,36). Correlations between yield and stand density are usually low in young stands, but increase as the stand ages (58,71).

Indirect Effects of Tillage

Alfalfa growth habit and yield are genetically determined, but environmentally influenced. Environmental changes, either on a macro or micro scale, elicit plant responses (5, 22,53). Tillage can affect the field environment in numerous ways. Among these are root structure, soil temperature, fertility, plant extract inhibition and disease.

Root Structure

Soil environment is a major determinant of alfalfa root structure (53,64). Although alfalfa is described as a deep, tap-rooted perennial, it shows considerable variability in rooting habit (11,18,37,47,63,64,68). Differences in number and size of branch roots and rhizomes occur among individual plants of a cultivar and among cultivars.

Most alfalfa roots are located in the top 20 cm of soil (15,37). Lamba et al. (37) found that alfalfa contained more roots in the upper 20 cm of soil than smooth bromegrass or timothy (*Phleum pratense* L.). They also showed that artificial aeration of a silt loam soil to 20 cm greatly increased root growth of both alfalfa and smooth bromegrass. Oxygen deficiencies can reduce root growth by either reducing turgor pressure or by increasing cell wall constraints (66).

Cohen and Strickling (10) reported that moisture removal by alfalfa was most intensive in the top 24 cm, even when soil moisture tension was lower at greater depths. However, Evans (15) found that root depth did not affect preferential moisture uptake by alfalfa. Taylor (66) reported that the absorption of water per unit length of root was the same for deep and shallow roots, so the proportion of roots in an area of available moisture determined water use patterns. Thus, the relatively shallow, fibrous root system of alfalfa supplies much of the plants' water requirement when moisture is available near the surface.

Plant spacing influences rooting pattern and plant survival of alfalfa. Healthy alfalfa plants are maintained in close plantings during years of abundant precipitation. However during drought conditions, survival in stands three or more years old is best when plants are more liberally spaced (18).

Normally, crown and root size rapidly increase during the first three to four years of growth (18,68). Number and size of alfalfa lateral roots increases as space becomes available (18). Plant spacing influences root size and type more than plant age (18,68).

Thinning alfalfa stands after the seeding year promotes increased root development of surviving plants (18,53). Plant thinning is most efficient when it occurs in the seeding year or shortly thereafter. Greater abnormalities occur in root growth when thinning is delayed (18).

Some strains of alfalfa can develop aerial shoots from severed root segments (18,63). In 1946, Garver (18) observed this phenomenon in 'Ladak' plants that had been severed by plowing. Vigorous plants developed from both tap and branch roots of severed plants. Experiments by Smith (63) in 1950 supported Garver's observations. He found bud and shoot formation on 8 cm root segments of Ladak alfalfa and on some *Medicago falcata* L. strains. Over 30% of the Ladak root segments cut from roots as deep as 18 cm below the cotyledonary node produced vigorous aerial shoots. Shoots were produced most often when root reserves were high.

Soil Temperature

Tillage causes soils to warm faster, and greatly increases the temperature fluctuations near the soil surface (47).

Field studies on plant response to root zone temperatures have been inconclusive because of complicating factors such as air temperature, photoperiod, humidity, and moisture regime (53). Kinbacher and Jensen (33) found a 12C temperature difference between the soil surface and one meter above the soil. They concluded that air temperatures were of little use in studying the early season growth of alfalfa and temperate grasses.

Alfalfa shoot and root growth is affected by soil temperature. Shoot growth yield increases as soil temperature increases to 28C (21). However, maximum root growth occurs at root zone temperatures of 12C to 18C (21,26,40,49). This indicates that alfalfa root growth in temperate climates is greatest in early spring and late fall (21). Warm soil surfaces encourage branched root development in the surface horizon (47).

Cool season grasses begin rapid growth at a lower soil temperature than does alfalfa (8,31,47). Optimum soil temperatures reported for top and root growth of most temperate grasses are about 20C and 10C, respectively (50,52). In dry conditions, grasses can use limited early season soil moisture before alfalfa commences rapid growth. Rapidly rising soil temperatures in the spring increase the competitive advantage of alfalfa over cool season grasses.

Nutrient conversion rate in the soil and subsequent plant uptake is affected by soil temperature. Low temperatures retard uptake of potassium (K), magnesium (Mg), phosphorus (P), and nitrogen (N) (23,24,52). Root zone temperature influences availability of P more than N (21). Reduced soil temperature usually requires increased P requirement to produce a given response in many species (40). Increased P fertilizer rates can partially compensate for adverse growing conditions created by low soil temperatures in alfalfa fields (40,47,49).

Nielsen et al. (49) demonstrated an increase in alfalfa root yield up to 1000% by the addition of P at low soil temperatures. They showed that low soil temperature repressed root growth more than top growth. Moisture and nutrient uptake by alfalfa is ineffective during periods of very slow root growth (23).

The percentage of P and N in alfalfa tops and roots increases as soil temperature increases (21,49). Tillage normally increases soil temperature and facilitates the breakdown of organic compounds. This may make N and P more available to alfalfa (49).

An increase in soil temperature does not hasten alfalfa maturity because flower initiation is mostly a function of foliage temperature and photoperiod (21).

Variation among alfalfa plants and among cultivars in their response to soil temperature have been noted (21,24,40,47).

Fertility

When in competition with grass, alfalfa competes well for P, but not for sulfur (S) and K (8). Inability to compete for K may account for much of the repressive effect of grasses upon legumes (8). Alfalfa roots have a cation-exchange capacity nearly double that of roots of common perennial grasses (8). Relatively large amounts of available K and P are required for new crown bud formation in alfalfa (3). Few crown buds and stems are produced when these elements are deficient (11) and root growth is severely reduced (60).

Alfalfa absorbs P most efficiently from the soil surface to an 8 cm depth. In an alfalfa-smooth bromegrass field, where fertilizer was surface broadcast, the smooth bromegrass obtained a greater percentage of its P from the fertilizer than did alfalfa. However, when P was placed 8 to 16 cm deep, alfalfa absorbed two to three times more P than smooth bromegrass (38). Neller and Hutton (46) reported that P placement to 16 cm had no effect on growth of sodded grasses when compared to surface placement of P.

Brown (3) found that the percentage of P in alfalfa tissues increased gradually with additions of P, but differences were smaller than increased growth rate. Phosphorus becomes less available to alfalfa as the stand ages because it becomes soil-bound (3).

Nitrogen requirements of healthy, vigorously growing alfalfa are normally met by a symbiotic relationship with *Rhizobium meliloti*. Nitrogen fertilizer added to grass-alfalfa mixtures usually increases the percentage of grass and decreases alfalfa's contribution to the mixture (8,28,30,32). Brown (3) reported that N fertilizer increased both alfalfa yield and stand density ratings (space occupied by alfalfa plants) when added to fields with declining stands and non-vigorous plant growth. This indicated that N deficiencies may be limiting alfalfa growth due to poor N fixation in older plants.

Underground transference of N from legumes to associated grasses can occur by sloughing and decay of nodules and plant residues, and by direct excretion of N from the intact root system, mainly in the form of aspartic acid and related compounds (8,61). Simpson (61) reported that N release after plowing alfalfa was small as compared to N release of living alfalfa. Organic N accumulators in the soil under a legume-grass mix provides much of the N for the grass (61). Organic residues mineralize slowly providing long-term transference. Tillage can increase the rate of organic mineralization under favorable environments (5).

Plant Extract Inhibition

Numerous scientists have investigated the influence of plant extracts and soil residues on germination and growth of crops (2,25,35,48,67). Direct excretion of growth inhibitors and toxic compounds produced by plant decomposition can affect alfalfa growth (48). Both factors could be influenced by tillage.

Quackgrass (*Agropyron repens* [L.] Beauv.) extracts have deleterious effects on germination and seedling growth of alfalfa (35,67). Smooth bromegrass produces a substance inhibitory to its own growth (auto-toxic) which contributes to the sod-binding condition observed in aging smooth bromegrass fields (2).

Alfalfa extracts inhibit germination and establishment of many grasses and legumes and are least inhibitory to alfalfa (48). However, Jensen et al. (25) reported that seeding alfalfa into a field recently plowed out of alfalfa resulted in poor vigor of new alfalfa seedlings as compared to seeding alfalfa on fallow soil, even though both soils were sterilized.

Disease

Alfalfa is susceptible to crown, root and vascular diseases in which the pathogen is introduced from the crown and root area (19). Some of the most important diseases include: bacterial wilt (*Corynebacterium insidiosum* (McCull) H. L. Jens.); Anthracnose

(*Colletotrichum trifolii* Bain.); Phytophthora root rot (*Phytopherora megasperma* Drechs.); Verticillium wilt (*Verticillium albo-atrum* Reinke and Berth); and Fusarium root rot (*Fusarium* spp.).

Crown and root damage caused by frost heaving, nematode feeding, and/or harvesting can increase the incidence of these diseases (19,39,55,57). Intentional wounding of the root and/or crown has been successfully used as a screening technique in the development of resistant varieties (29,56,70).

Certain species of *Fusarium* (*F. solani* [Mart.] appel and Wr., *F. roseum* Lk. emend Snyd. and Hans, and *F. oxysporum* Schlecht) have been consistently associated with most types of root and crown deterioration in alfalfa (33). Roberti (57) found that necrotic areas were frequently associated with wounds in the crown or root surface, and *Fusarium* spp. were nearly always isolated from these areas. However, the same fungi are commonly isolated from roots showing no lesions (51). Chi et al. (9) demonstrated that *Fusarium* spp. are capable of invading non-injured root tissue.

Although the presence of root wounds increases root invasion by soil fungi, disease symptoms are not consistently associated with wounded tissue (39). Leath et al. (39) showed that callus formations often seal off decay sites in wounded tissue. High K plant levels are necessary for adequate wound healing.

O'Rourke and Millar (51) established that *Fusarium* spp. colonized alfalfa seedlings soon after germination, and developed a parasitic relationship with vigorously growing plants. The potential of these fungi as pathogens depends upon environmental factors which weaken or stress the plant (39,51,57,60). One such factor could be tillage.

CHAPTER III

RENOVATION OF OLDER ESTABLISHED ALFALFA STANDS

Materials and Methods

Experiments were established in the spring of 1981 at three locations. All studies were identical in design but differed in initial forage composition. Two of the studies were located on the Northwestern Agricultural Research Center at Kalispell, Montana, and the third study was located on the Montana State University Animal Science Farm at Bozeman, Montana.

Treatments were arranged in split plot, randomized complete block designs with four replications. Tillage and herbicide treatments were randomly assigned as main plots (18.4 X 9.2 m). Each main plot contained four sub-plots (4.6 X 9.2 m) consisting of: 1) plots treated one year only (1981); 2) plots treated for two consecutive years (1981 and 1982); 3) plots treated in three consecutive years (1981, 1982, and 1983); and 4) plots left untreated in all years (control).

The experiment was designed to continue for three years in order to determine long term treatment effects. However, only 1981 and 1982 data are included herein.

Tillage treatments consisted of: 1) deep one-way tillage (10 cm) with a field cultivator containing multiple spring loaded shanks (points); 2) shallow one-way tillage (5 cm) with a field cultivator; and 3) one-way tillage with a tandem disk set 8 cm deep. At Kalispell, both deep and shallow tillage treatments were applied with a Vibra-shank[1] cultivator

[1] Mention of a trademark, proprietary product, or vendor is included for the benefit of the reader, and does not imply endorsement by Montana State University or the Montana Agricultural Experiment Station to the exclusion of other suitable products.

which has narrow shanks (4 cm) spaced every 15 cm along the tool bars. A light harrow is also attached at the rear of this implement. At Bozeman, a Triple-K[1] cultivator was used for deep and shallow tillage. The Triple-K is similar to the Vibra-shank, but the shanks are 2.5 cm wide and spaced every 10 cm along the tool bars.

The three herbicides were 1) pronamide (3,5-dichloro(*N*-1,1-dimethyl-2-propynyl)-benzamide), at 2.24 kg AI ha^{-1}; 2) metribuzin (4-amino-6-(*tert*-butyl-3-(methylthio)-*as*-triazin-5(4*H*)-one), at 1.12 kg AI ha^{-1}; and 3) terbacil (3-*tert*-butyl-5-chloro-6-methyluracil), at 1.12 kg AI ha^{-1}. These herbicides are soil activated and labeled for dormant application to established alfalfa stands.

At Kalispell, herbicides were applied with a tractor mounted sprayer with nozzles spaced 50 cm apart on a 4.6 m boom. A 3.6 m hand held boom with nozzle spacing of 46 cm was used at Bozeman. Total spray solution was 32.2 L ha^{-1} at all locations.

Kalispell (Experiment I)

This study was conducted on a six-year-old stand of 'Thor' alfalfa. The experimental area encompassed Creston silt loam (Udic Haploboroll) and Flathead fine sandy loam (Pachic Udic Haploboroll) soils.

Perennial grasses invading the alfalfa stand were Kentucky bluegrass (*Poa pratensis* L.), quackgrass, orchardgrass (*Dactylis glomerata* L.), smooth bromegrass, and redtop (*Agrostis alla* L.). Annual grasses present were cheatgrass and bulbous bluegrass (*Poa bulbosa* L.). Total grass composition, as obtained by occular ratings, was approximately 25%. Variation within the experimental area was high, with occular grass ratings ranging from 10–60%.

Broadleaved weeds present were dandelion (*Taraxacum officinale* Weber), pigweed (*Amaranthus retroflexus* L.), chickweed (*Stellaria media* [L.] Cyrillo), lambsquarter (*Chenopodium album* L.), corn gromwell (*Lithospermum arvense* L.), and tansy mustard (*Descurainia pinnata* L.).

Herbicide and tillage treatments were applied on March 18 and March 23, respectively, in 1981. Soil and air temperatures were 6.2C and 3.3C, respectively, on March 18 and 6.9C and 4.8C on March 23. Alfalfa growth was approximately 4 cm high at time of treatment. Perennial grasses had about 6 cm of new growth.

Forage was harvested with a sickle bar mower on July 2 and August 11, 1981, from a 4.46 m^2 area in each plot, and weighed immediately. A random 500 g sample was obtained from the harvested forage of each plot, dried at 38C, and reweighed to determine moisture content. Dry matter yield was calculated for each plot and reported as kg ha^{-1}.

Crop year precipitation (September, 1980–August, 1981) was 59.4 cm. The experiment was sprinkler irrigated on July 29, 1981 with 4.6 cm of water.

In response to low first cutting yields for all treatments, the experimental area was fertilized on July 13, 1981 with 42 kg ha^{-1} N, 75.7 kg ha^{-1} P_2O_5 and 31 kg ha^{-1} S.

Plots receiving herbicide treatments for the 1982 growing season were sprayed on November 3, 1982. Soil and air temperatures were 12.2C and 8.2C, respectively. New growth was apparent on both alfalfa and grass plants at the time of tillage treatments.

Forage was harvested on June 25 and August 11, 1982. A small plot flail harvester (Rem Mfg. Co., Swift Current, Canada) was used to harvest 2.97 m^2 of forage per plot. Other procedures were the same as in 1981.

Crop year precipitation was 46 cm in 1982. The experimental area was sprinkler irrigated once with 4.6 cm of water on July 26.

Kalispell (Experiment II)

This study was conducted on an eight-year-old stand of 'Ladak' alfalfa established on a Yeomon gravely loam (Udic Haploboroll) soil.

The stand had been severely invaded by perennial grasses and broadleaved weeds. Kentucky bluegrass accounted for nearly 40% of the stand by occular ratings. Other perennial grasses invading the stand included orchardgrass, meadow foxtail (*Alopecurus pratensis* L.), and smooth bromegrass. Although quackgrass and annual grasses (cheatgrass and bulbous bluegrass) were present, they were not a significant problem. Grass composition in the stand ranged from 20–70%.

Dandelion was the most serious broadleaved weed problem, although most of the species listed for Experiment I were also present.

Dates and methods of treatment application for this study are identical to those described for Kalispell Experiment I, in both 1981 and 1982. The soil temperature was 6.1C when both herbicide and tillage treatments were applied in 1981. In 1982, the soil temperature was 8.2C when the tillage treatments were applied.

Forage was harvested July 9 and August 25, 1981. In 1982, harvests were taken on June 24 and August 11. The study was not irrigated in 1981. In 1982, plots were sprinkler irrigated on June 29 and August 6 with 4.6 cm of water at each irrigation.

Bozeman

This study was conducted on a six-year-old forage stand initially seeded to alfalfa (cultivar unknown) and intermediate wheatgrass. Stand composition was approximately equal portions of grass and alfalfa. The experimental area was located on a Bozeman silt loam (Agric Pachic Cryoboral) soil.

Although intermediate wheatgrass was the dominant grass species, smooth bromegrass, orchardgrass, and quackgrass had also invaded the stand. Cheatgrass was present, but was not a significant problem.

Broadleaved weeds included dandelion, chickweed, shepherds purse (*Capsella bursa-pastoris* [L.] Medic.), field pennycress (*Thlaspi arvense* L.), and common milkweed (*Asclepias syriaca* L.).

Herbicide and tillage treatments were applied April 10 and April 16, 1981, respectively, when alfalfa plants had just begun new growth. Soil and air temperatures were 9.4C and 11.2C, respectively, on April 16.

In 1981, a 3.72 m^2 area was harvested on July 8 with a small plot flail harvester (Rem). A moisture sample was taken for each plot and dry matter yield calculated as previously described.

Crop year precipitation was 57.4 cm in 1981. The field was flood irrigated in early August. Because of the variability caused by uneven irrigation, a second harvest was not taken in 1981.

Alfalfa weevil (*Hypera postica* Gyllenhal) damage occurred in 1981. All treatments were affected similarly.

In 1982, herbicide treatments were applied on April 24. Tillage treatments were applied on April 27 when alfalfa had about 4 cm of new growth. Soil and air temperatures were 8.1C and 17.4C, respectively, on April 24, and 8.3C and 16.3C, respectively, on April 27. Forage was harvested on July 12 and October 16, 1982. Harvest procedure in 1982 was identical to that described for 1981 at Bozeman.

Crop year precipitation was 58.8 cm in 1982. The experiment was not irrigated in 1982.

Soil Test

Soil samples were taken to a depth of 23 cm in control plots at the time of initial tillage treatment in 1981 at all locations. Soils were sampled again one week after treatment in tillage and control plots. Thereafter, soil samples were taken every two weeks until early June. In 1982, soil samples were not taken because of insignificant results obtained from analyses of 1981 soil sample data.