NO-TILL PERENNIAL FORAGE ESTABLISHMENT

IN WESTERN MONTANA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Animal and Range Sciences

MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 2005

APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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August 2005

ACKNOWLEDGEMENTS

I would like to express special thank to my mentor Dr. Dennis Cash for providing me with financial support and professional input to pursue this thesis.

Also, I want to express a special acknowledgement to Dr. Andy Lenssen, Dr. Bok Sowell, Dr. Ray Ditterline and Dr. Patrick Hatfield for their valuable advice as members of my committee and as teachers during my class work. To Dr. Jack Martin for his valuable advice in the statistical analyses of the data.

I would also like to thank the Nutritional Center staff for their help in the field with the clipping of the plots and in the lab to process the forage samples. Thanks to Byron, Bernard, and Bill for providing equipments and tools to do my fieldwork.

I am very thankful for the financial support provided by the Instituto de Investigaciones Agropecuarias, Chile during these two years.

Finally, I would like to express my deepest thanks to my wife, Mariela, and our two sons, Vicente and Tomas, for their love, and understanding.

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ABSTRACT

No-till forages offer an opportunity to convert old forage stands to high-yielding pastures. Sod, soil water control and forage species are key factors in determining the success of no-till application. Experiment 1 was conducted to determine optimum vegetation control and moisture on alfalfa in the spring. In experiment 2, adapted grasses and legumes were compared under tilled and no-till seedbed preparation to assess their performance. In Experiment 1, the effects of timing of glyphosate [N-(phosphonomethyl) glycine] application, two alfalfa cultivars (including a roundup ready alfalfa) and five irrigation levels were investigated in Bozeman, MT in an old alfalfa stand in a subirrigated location. Experiment 2 was planted contiguous to Experiment 1; 11 forage species were planted in early summer (24 June) and late summer (28 August) under irrigation. During establishment year, applying glyphosate four weeks before planting resulted in a higher plant population and alfalfa yield than all the other treatments. Differences were not detected in the post-establishment year. The establishment of no-till alfalfa was very low in the second planting year, likely due to wet and colder weather. Alfalfa yield during the establishment year responded significantly to irrigation level and the effect was not relevant for yield in the post-establishment year. No-till legumes and grasses in the summer resulted in yields similar to those following conventional seedbed preparation although higher in early summer than late summer. Grasses had about four times higher yields than legumes in part, because post-emergence broadleaf control was less effective in legumes. Late summer planting resulted in high weed encroachment and low target forage yields. These results indicate that delaying planting four weeks after spraying with glyphosate and controlled irrigation is a promising no-till alfalfa planting system but highly dependent on establishment weather conditions. No-till grasses offer an opportunity to impact the wide use of no-till to increase yield in an old alfalfa stand, but post-emergence weed control would be a key management especially in legumes.

INTRODUCTION

No-till planting of forage species offers opportunities for converting old forage stands to high-quality grass or legume pastures. It has been a successful establishment method for alfalfa (*Medicago sativa* L.) and other species, especially in combination with herbicide to suppress the resident vegetation, but it has rarely been used in Montana. This technique could be used to improve production of pasturelands and rangelands with less disturbance and expense compared with conventional tillage planting methods.

Successful establishment of forage species into sod is limited by competition for light and water between the resident species and forage seedlings. Studies have shown that the biomass of resident species, timing of herbicide application, soil water content and planting season are key factors in successful establishment of no-till forages. Therefore, adequate sod control and adequate soil water content after planting could improve the establishment of recently planted seeds and yield during the establishment year. Important differences in no-till planting methods may exist among species, which impacts the wide use of this planting technique.

The development of successful no-till practices could extend a more environmentally friendly and cost-effective forage establishment system in western Montana and dramatically enhance the production of high quality forage.

LITERATURE REVIEW

Forages in Montana

The primary forage resources in Montana for livestock are the 15.5 million ha of non-Federal range and pastureland (USDA-NASS, 2002). Pastureland and forage crops that include annual and perennial legumes and grasses are grazed by livestock or stored as hay.

Hay production in Montana involves 950 thousand ha and more than 350 million dollars per year in value (USDA-NASS, 2004). Alfalfa is the most important forage crop, but native or introduced forage species showed potential to improve forage production in dryland (Blunt, 2001), and under irrigation (Cash, 2005a,b).

Alfalfa

Alfalfa is the most important forage crop in Montana, although its longevity is limited due to declines in plant population. Alfalfa stands decrease due to winter injury, harvest or grazing management, diseases, insect damage or drought, losing their ability to compete with weeds. Thick stands of high quality forage species are critical to the success of haying and grazing operations. An alfalfa stand of more than 250 stems m^{-2} suppresses weeds (Ward et al., 1990) and when stem densities decline below 200 stems m^{-2}, alfalfa production is significantly reduced (Cummings et al., 1999). According to Orloff and Putnam (1997) stands below 30 - 40 healthy plants m^{-2} are no longer profitable in California. In Montana data are not available to guide decisions making for renovation based on plant density, but it could be less than eastern U.S. areas because of low yield potential in the semi arid west.

In Montana, alfalfa is known for its ‘geriatric stands’ (Dixon et al., 2005) but normally the more productive fields are under irrigation in short duration crop rotations. In contrast, stand longevity is a major goal for ranchers with dryland and even some irrigated or subirrigated stands. The timing of alfalfa stand replacement depends mostly on plant density and yield potential. However, many Montana producers delay renovation decisions due to economic considerations.

Grasses and Other Legumes

Native or introduced species have potential to improve pasturelands and rangelands. Blunt (2001) evaluated 29 grasses in dryland over three years at three locations in Montana. Overall, intermediate wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey) and pubescent wheatgrass (*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey subsp. barbulatum (Schur) Barkworth & D.R. Dewey) varieties out-performed the other cultivars in terms of yield, but wildryes had better forage quality.

Under irrigation, meadow bromegrass (*Bromus riparius* Rehm), festololium (*L.multiflorum* × *F. arundinacea* hybrid), tall fescue (*Festuca arundinacea* Schreb.) and smooth bromegrass (*B. inermis* Leyss.) were the most productive species during three years after planting (Cash, 2005a). Yields were higher in Kalispell than in Bozeman due to higher rainfall and cooler temperatures.

Sainfoin (*Onobrychis viciifolia* Scop.) has a high yield potential, similar to that of alfalfa under irrigated conditions (Cash, 2005b). Other legumes, including birdsfoot trefoil (*Lotus corniculatus* L.) and cicer milkvetch (*Astralagus cicer* L.) are adapted for dryland and irrigated conditions. Over 4 years, the annual average yields of different varieties of sainfoin, alfalfa, birdsfoot trefoil and cicer milkvetch were 13.0, 10.6, 7.0, and 5.1 ton ha^{-1}, respectively.

In summary these species are the best for dryland or irrigated conditions in western Montana and may increase productivity and improve seasonal distribution of forage in pastures dominated by less productive species.

Stand Establishment

In Montana, declining productivity of pasture or hayland might be reversed with the introduction of more desirable grass or legume species. The most common method of forage stand renovation consists of breaking the hayfield or pasture with tillage followed by crop rotation to an alternative annual crop. Dryland fields are typically fallowed (mechanical or chemical) for one year for moisture conservation prior to planting (Holzworth et al., 2003).

Conventional seedbed preparation by conventional tillage may dry out the seedbed and increase the risk of soil erosion (Sturgul et al., 1990). In contrast, low establishment costs and erosion control can be achieved with low disturbance seeding techniques (Koch, 1991). No-till forage renovation (or sod-seeding) is widely used in other areas (Tesar and Marble, 1988), but it has rarely been used in Montana due to lack of equipment or expertise.

Stand longevity is more important in long-term rotations for livestock operations compared to intensive short-term hay rotations with other cash crops. Therefore long-term persistence is more important in dryland, high-rainfall areas, or under subirrigated conditions where rotations are longer. For these reasons, appropriate no-till techniques for livestock producers are needed to improve stand establishment of perennial forages.

Conventional Planting

Conventional tillage removes competition from established forages or weeds and provides a good environment for establishing new pastures. However, conventional tillage destroys beneficial plants, removes pastures from use for a relatively long period of time, and under dryland conditions, increases risk of stand establishment failure (Johnson, 2004).

Conventionally tilled seedbed preparation for reseeding is commonly used for irrigated conditions under crop rotation. Tilling has been often impractical due to economic considerations or because the terrain is too wet, rocky or steep (Tesar and Marble, 1988).

No-till Planting

No-till forage seeding is referred to as a conservation sowing system, which allows seeding of improved forages without tillage. No-till is also known as sod-seeding or interseeding (Koch, 1991). No-till planting has a greater risk of seedling mortality as a result of competition from resident plants compared to conventional tillage planting techniques, but reduces the risk of erosion (Baker et al., 1996). Sod-seeding includes planting into a sod or in a stubble of small grains, and generally involves the use of herbicides to suppress grasses and broadleaf weeds for successful establishment (Tesar and Marble, 1988; Wolf et al., 1996).

This technique is used to introduce legumes into existing grass pastures, to completely replace an existing species, or to increase species diversity. Compared with conventional methods of seeding, no-till seeding: 1) is less expensive and less time-consuming, 2) eliminates the risk of soil erosion due to slope or wind, and 3) may allow for grazing during the renovation period (Baker et al., 1996). Surface residue or sod protects the soil from rainfall impact and thus reduces splash erosion. In addition, surface residue slows the speed of water flowing down a slope, allowing more time for the water to infiltrate in the soil (Simmons, 2002).

The no-till planting method is a potential alternative for Montana ranchers to: 1) improve the species composition of rangelands and/or reduce weed populations (Allen, 1994; Johnson, 2004; Rose et al., 2001), 2) increase yield and quality of pastures (Welty et al., 1983; Koch, 1991; Cuomo et al., 2001), hayfields (George et al., 1995), and rangelands (Mortenson, 2003). In Montana, sod-seeding had been tested primarily with alfalfa (Welty et al., 1983), and with a limited number of improved and native grasses and forbs in dryland (Johnson, 2004).

Currently no-till planting into herbicide-killed sods and other interseeding techniques may work in sub-irrigated or irrigated conditions, but it is not recommended for dryland pastures in Montana or Wyoming (Holzworth et al., 2003).

Factors Affecting No-till Seedling Establishment

The major constraints to establishing no-till forages are competition for resources such as light, soil water and possible allelopathic effect between seedlings and the resident vegetation. Reducing competition from the resident vegetation is essential for successful no-till planting, because light and soil moisture are critical for the emergence and early growth of seedlings.

Light

Alfalfa seedlings introduced into a sod are exposed to a different micro-environment than alfalfa seedlings established with a clear seeding. Cooper (1967) observed that under shaded conditions, alfalfa and birdsfoot trefoil partitioned more dry matter into shoots than roots. This response could severely limit the ability of a shaded seedling to compete with indigenous vegetation for soil water (Groya and Sheaffer, 1981).

Using herbicides to suppress the sod prior to planting increases temperature, soil water and alfalfa establishment compared to unsprayed areas (Allen, 1994). Light can also have a negative effect on mollusks. Welty et al. (1981) attributed improved sod-seeded ladino clover (*Trifolium repens* L.) establishment following sod-suppression to the fact that sunlight was able to penetrate to the soil surface, dry out the furrow and provide a less favorable environment for slugs (*Agriolimax reticulatum* Muller). Slugs can damage seedlings reducing stand and may defoliate established stands that may delay plant development.

Soil Water Availability

Bowes and Zentner (1992) concluded that adequate soil water was the most important factor controlling the establishment of sod-seeded alfalfa into bluegrass (*Poa spp*. L)-dominated pasture in east-central Saskatchewan, Canada. Plant population was better in high rainfall years, and yield of alfalfa were correlated with precipitation during April to June of the establishment year ($r = 0.52$, $P<0.04$). Allen (1994) found that sod suppression was more important in the site where soil water was more limiting. This corroborates the importance of precipitation immediately following seeding alfalfa into a sod. Germination and emergence of alfalfa sod-seeded into a Kentucky bluegrass (*P. pratensis* L.) sod was influenced more strongly by the amount and distribution of precipitation immediately following seeding than soil and air temperature (Taylor et al., 1969).

The importance of moisture status at planting has been related to plant establishment, yield and diseases. Schellenberg and Waddington (1997) found significant differences in seedling establishment of alfalfa over crested wheatgrass (*Agropyron desertorum* [Fish.] Shult.) sod among three years although precipitation was plentiful during germination period. Other factors within plot microclimates prevented establishment, like evaporation of the soil surface which decreased with amount of plant residue or soil disturbance.

After establishment, an adequate water status during summer allowed alfalfa plants to accumulate nitrogen reserves by increasing taproot mass resulting in rapid shoot growth rate and high number of crown buds the following spring (Juster et al., 2002). This aspect may have important implications in winter survival and yield.

Resident Vegetation Control

Reducing competition from the resident vegetation is essential in sod-seeding, especially when a full stand of target forage is desired. Alfalfa seedling density and vigor are directly related to the degree of sod control (Allen, 1994; Taylor et al., 1969; Vogel et al., 1983).

Mechanical

Mowing depresses root growth because less photosynthesis can take place and the root reserves are used for new growth (Dibbern, 1948). Mowing early in the spring can weaken plants to a greater degree, as plants depend on the root reserves as food source until new growth and photosynthesis take place (Ehrenreich and Aikman, 1963). Clipping is a conservative method which does not disturb the topsoil but can suppresses the resident vegetation. Taylor and Allison (1983) reduced the competition from the resident vegetation by mowing, and found that height and frequency of clipping, and the position of the growing point of resident plants influenced the degree to which the resident vegetation was suppressed.

Taylor and Allison (1983) reported that alfalfa, birdsfoot trefoil and red clover (*T. pratense* L.) may be successfully sod-seeded into mowed stands of timothy (*Phleum pratense* L.) and smooth bromegrass but less successfully into orchardgrass and tall fescue (*Festuca arundinacea* Schreb.), once the competition from the resident vegetation was reduced by clipping treatments.

Physical suppression methods have not always been successful when existing vegetation provided intensive competition for light and nutrients. In Quebec, Canada, sod-seeded legumes into a pasture utilizing different forms of sod-suppression in general did not improve total biomass yield in the first two years. However, chemical treatment reduced total yield and resulted in increased weed encroachment (Seguin et al., 2001). The authors noted that mowing or sheep grazing has potential but cannot be considered a complete alternative to herbicide suppression, but long-term evaluations are needed.

Chemical

Chemical sod control is generally more successful than shallow tillage and planting immediately. Bowes and Zentner (1992) in east-central Saskatchewan, reported that alfalfa could be sod-seeded directly into low yielding pastures with high percentage of *Poa* spp. following the suppression of the resident vegetation with glyphosate, resulting in more established alfalfa plants than following a rototilling treatment. Herbicide suppression with glyphosate enhanced better red and white clover yields, clover content and quality in post-renovation years than mowing or sheep grazing in a smooth brome dominated sward (Seguin et al., 2001).

Herbicide control is generally superior than mowing the sward when existing vegetation provides extensive competition for light and nutrients (Neumaister, 1994; Bentley and Clements, 1989; Welty et al., 1983;). Non-selective contact herbicides like paraquat [1, 1',dimethyl-4,4'-bipyridinium ion] or non-selective translocated herbicides like glyphosate [N-(phosphonomethyl) glycine] have been used to control sod, but glyphosate kills most vegetation and has a longer duration of suppression than paraquat (Squires, 1976).

Glyphosate application appears more suitable for sod control than paraquat (Welty et al., 1983; Gobin, 1994) especially when perennial species are the main component in the sod (Neumaister, 1994). In western Montana Welty et al. (1983) evaluated 26 off-station trials and concluded that glyphosate (0.8 to 2.5 kg a.i. ha^{-1}) provided better sod control than paraquat (0.8 kg a.i. ha^{-1}).

In western Oregon, Neumaister (1994) found that glyphosate was a good choice to introduce perennial ryegrass (*Lolium perenne* L.) into pastures dominated by undesirable perennial species, but clovers and other perennial grasses were suppressed. Paraquat produces a temporary suppression of sod but allows regrowth that reduces seedling development (Welty et al., 1983) or enhances weed encroachment of perennial weeds (Rioux, 1994). Therefore, paraquat can be used to suppress annual weeds if a balance of clover and the sod-seeded grass species is desired and undesirable perennial grass weeds are not present (Neumaister, 1994).

Some sod species are easier to control than others, demonstrating tolerance to herbicides, which is an important limitation of chemical control. Vogel et al. (1983) in an alfalfa sod-seeding experiment, reported that smooth bromegrass survived better than meadow bromegrass, intermediate wheatgrass, tall wheatgrass and orchardgrass in sod, demonstrating both within and among species for tolerance to glyphosate at a rate of 1.7 kg ha^{-1}.

There is some evidence that the application of glyphosate (1.7 kg a.i. ha^{-1}) did not control tall fescue on a wetland pasture consisting of Kentucky bluegrass-orchard grass (*Dactylis glomerata* L.)-tall fescue (*Festuca arundinacea* L.), where competition from the grass affected the establishment and yield of alfalfa in a non-till system (Welty et al., 1983). In Georgia, Hoveland et al. (1996) reported that 0.14 kg a.i. ha^{-1} paraquat adequately controlled a tall fescue sod for successful alfalfa no-till planting in September. In Saskatchewan, Canada over two years in six experimental sites, the mixture of glyphosate and 2,4-D (2,4-Dichlorophenoxyacetic acid) controlled the vegetation less than glyphosate at 2x rate (2.2 a.i ha^{-1}) (Waddington, 1992).

Allelopathy

Residue from the resident vegetation can reduce establishment of sod-seeded seedlings due to chemical interference or physical impedance. Many plants contain chemical compounds released by leaching, root exudation or residue decomposition that can be toxic to other species (allelopathy) or to itself (autotoxicity), which inhibit or delay germination and growth (Miller, 1996). These allelochemicals may be of importance in minimum-tillage and no-till agriculture, where crop residues are left on the soil surface after harvest, or in intensive systems such as intercropping. Chung and Miller (1995) in laboratory and greenhouse experiments found the most inhibitory effects of alfalfa germination and growth of alfalfa where from smooth bromegrass, orchardgrass and grain sorghum (*Sorghum bicolor* (L.) Moench ssp. *bicolor)* residues.

The extent of allelopathic effects from decaying pasture is not fully understood, but it declines over time. Toai and Linscott (1979) showed that alfalfa seeding development and growth were inhibited by toxins released from dried quackgrass (*Agropyron repens* L. Beauv.) rhizomes and leaves, but the degree of phytotoxicity to alfalfa decreased with time. From three to six weeks after herbicide treatment were necessary to avoid deleterious effects on seedlings. Quackgrass is one of the most important weed problems in alfalfa, which presence encourages stand renovation. The allelopathic effect of quackgrass may be related to the presence of indole-3-acetic acid in the rhizomes that affect germination and growth of alfalfa (Korhammer and Haslinger, 1994). Weston and Putnam (1986) indicate that toxicity may occur after suppressing quackgrass with glyphosate prior to seeding, and microorganisms play an important role in both activating and degrading the toxic principle of this weed. The authors noted that even when quackgrass is destroyed with an herbicide, the toxic principle remains active. Thus suppression of vegetative quackgrass early in spring may cause stronger allelopathic effect on alfalfa than when the weed is suppressed the previous fall.

Although autotoxicity have been indicated as an important limitation in sod-seeding alfalfa, the extent of this effect appears to be limited. Seguin et al. (2002) reported no evidence of autotoxicity in alfalfa during the establishment year when original stands were sprayed in the fall and plowed two weeks before planting. However, in some cases, a delayed autotoxic effect on yield was measured in the second year. Tesar (1993) reported that alfalfa was re-established without significant autotoxicity if seedings were made at least two weeks after plowing or three weeks after glyphosate application on established alfalfa or after seeding failure.

Allelopathy can be more problematic in no-till than in a tilled seedbed planting system because allelopathic compounds degrade slower (Roth et al., 2000) and especially with high residue levels (Miller, 1996).

Timing of Herbicide Application

The effectiveness of sod suppression by herbicide application is governed principally by timing and the developmental stage of the resident vegetation. Timing of herbicide application for interseeding is critical for sod control and for seedling development. Poor sod control occurs when growth activity of resident sod species was insufficient for adequate toxicity of the herbicide (Koch, 1991; Welty et al., 1981) or annual weeds had not germinated at the time of application (Neumesiter, 1994; Johnson, 2004).

Timing

Koch (1991) indicated that at least 10 to 13 cm of actively growing cool-season grass in the spring was necessary for satisfactory sod control in Wyoming. Low temperatures and slow plant growth could affect herbicide activity early in spring (Byers and Templeton, 1988). They found in Pennsylvania that mowing an orchardgrass sod was better than glyphosate application in a March seeding of alfalfa, but no differences were found in May, when growth of sod was higher. Peat and Bowes (1995) conducted trials to test the effectiveness of glyphosate applied at different growth stages. Their data show that spraying crested wheatgrass sod at 15 cm tall was much less effective than spraying at 8 to 15 cm.

Late spring application of herbicide may improve sod control, but soil water content may become more limiting for new seedlings. Increasing soil water content at seeding improves seedling emergence (Allen, 1994). Therefore, early control of resident vegetation may enhance soil water content but sward regrowth could be enhanced and post-planting weed control might be more difficult.

Fall herbicide application is another option for termination of old pastures stands that might be useful for spring sod-seeding in Montana. If an early spring sod-seeding is planned, Wolf et al. (1996) indicated that two applications of a non-selective herbicide were recommended, in the fall and just prior to seeding if regrowth or winter annuals weeds are present. However, two application of a non-selective herbicide has important economical and practical implications (i.e. spraying-planting interval).

Malik and Waddington (1990) found that early fall spraying with glyphosate followed by late fall sod-seeding resulted in better alfalfa establishment than fall spraying and seeding the following spring. These results likely occurred because dry conditions in spring when weed and established grasses start growth early and would have removed substantial amounts of water from the soil prior to the May planting date. Late fall planting might apply for grasses but not for legumes in western Montana due to low establishment and poor development for wintering (Smith, 1960).

Herbicide Application - Planting Interval

In some situations where herbicides provided adequate sod control, forage stand establishment may be inadequate. Suspected reasons for poor establishment in addition to limited water or light for seedlings are residual toxicity of non-selective herbicide.

Some studies have shown the need for two to four weeks delay following glyphosate application before no-till planting of alfalfa (Tesar, 1993; Mueller-Warrant and Koch, 1980; Delaney et al., 1984; Welty et al., 1981) or 14 days for ladino clover (Welty et al., 1983), two to three weeks in alsike clover (*T. hybridum* L.) and tall fescue, 10 days for grasses or 20 days for alfalfa (Campbell, 1976).

When the interval of spray-planting is short, toxins released from dying sod could also be potentially harmful to the germinating seed and seedlings (Neumesiter, 1994). Herbicide residual effects on germination of various forage species have been investigated. Segura et al. (1978) showed that glyphosate sprayed on annual ryegrass (*L. multiflorum* L.) and red clover with or without 5 mm of soil cover, reduced germination. However, Moshier and Penner (1978) reported that glyphosate applied over seed of two alfalfa cultivars did not reduce germination, but did reduce shoot length. Hurto and Turgeon (1979) found that Kentucky bluegrass thatch containing paraquat inhibited perennial ryegrass establishment, but glyphosate did not.

Toxic effects from herbicide residues that remain in the sod may affect emergence, but glyphosate degrades quickly in the soil and the effect decreases over time (Haney et al., 2000). Better stands and yields have been obtained by delaying planting after spraying, but soil water content may be more limiting in spring operations. For this reason, a one-step operation where the herbicide is applied through a spray boom attached to the drill might not be recommended for no-till planting. The future use of glyphosate tolerant forage species may overcome glyphosate toxicity and allow planting early after spraying or current spraying and planting.

Glyphosate Tolerant Alfalfa

Glyphosate-resistant crops, also known as Roundup Ready^{TM} (RR), have become an important part of annual cropping systems in the United States. In 2004, approximately 13% of corn (*Zea mais* L.), 85% of soybean (*Glycine max* (L.) Merr.), and 60% of cotton (*Gossypium hirsutum* L.) acreage was occupied by RR varieties (Van Deynze et al., 2004). The RR technology incorporates genetic resistance to glyphosate into crop plants by inserting a single bacterial gene that modifies 5-enolpyruvylshikimate-3-phosphate synthase, an enzyme essential for plant growth. Monsanto Inc. (St. Louis, MO) has used this technology to develop several RR crops and this technology was under review for potential release of RR Alfalfa in the USA (Fitzpatrick and Rogan, 2004). On 15 June 2005, Roundup Ready alfalfa^{TM} (RRA) was deregulated and glyphosate was approved for incrop application (Curran, 2005).

Roundup Ready alfalfa is being extensively studied by public and private researchers to develop management protocols and address environmental questions for this technology. Currently there are no peer-review publications available on RRA but some technical publications (Wilson, 2004; Van Deynze et al., 2004) and news articles have reported this technology (Burns, 2004; Wilkins, 2005). RRA provides an additional weed management tool for growers, the principal feature being its simplicity, flexibility, worker safety, and broad-spectrum weed control.

The RRA would enable the use of glyphosate for a full spectrum of weed control during establishment and improve alfalfa yields and forage quality due to reduced weed contamination (Wilson, 2004; Van Deynze et al., 2004). The RRA technology might readily be adapted to no-till seeding because seeding could occur immediately after glyphosate application with a single field entry. Further, glyphosate could be applied throughout the establishment season to suppress resident vegetation and emerging weeds (Wilson, 2004). To date, RRA has not been tested under no-till seeding conditions.

The RRA will expand weed control options available for alfalfa growers, potentially enhancing yield, hay quality, and profitability. RRA provides a simple option to minimize the risk of consumption of poisonous or unpalatable weeds by livestock, and it has the potential to improve animal welfare and production by increasing the feeding of pure, weed-free, high-quality alfalfa hay (Fitzpatrick and Rogan, 2004).

Toxicity and allergenicity studies of the new protein in feed have not been published, but other RR genetically modified varieties presented non-differences with non-transgenic control varieties in animal performance. RR cottonseed was evaluated in lactating dairy cows by Castillo et al. (2004) who reported no differences in milk production respect to conventional cottonseed. RR corn had no significant effect on nutritive quality and carcass characteristics on finishing steers (Erickson et al., 2003).

There are potential environmental benefits for RRA if current alfalfa herbicides present water quality or worker-safety concerns. Glyphosate is relatively environmentally safe because it has very slow mobility in soil and it is quickly degraded by microbes in the soil (Haney et al., 2000). These features reduce herbicide residual concentrations that could affect the subsequent crop and therefore plant-back restriction do not apply after using this chemical. The major concerns associated with RR technology are the potential for weed shifts and development of resistance by weeds. Also, potential gene flows during seed production to feral alfalfa, and market acceptance for exports have been major concerns related to RRA (Fitzpatrick and Rogan, 2004).

Effect of Irrigation on Forage Production

In 2003, 48% of Montana's alfalfa acreage was under irrigation, which yielded 75% of the alfalfa hay (USDA-NASS, 2004). Average alfalfa hay yields from 1993 through 2003 were

7.3±0.3 and 2.8±0.6 ton ha^{-1} for irrigated and dryland alfalfa, respectively. Experimental data revealed a high potential for irrigated alfalfa. Cash et al. (2005a) reported a yield performance of 19 alfalfa cultivars under irrigation (three locations) and dryland (two locations). Irrigated alfalfa yields for three years after planting ranged from 12.3 to 16.7 ton ha^{-1}, but in dryland conditions evaluated two years after planting ranged from 2.3 to 2.8 ton ha^{-1}, with differences among locations.

In western Montana alfalfa has a higher yield compared to other species either in dryland or irrigated conditions (Cash, 2005b). Sainfoin appears promising with yields similar to alfalfa under irrigated conditions (Cash, 2005b). Over four years, the annual average yields of different varieties of sainfoin, alfalfa, birdsfoot trefoil and cicer milkvetch under irrigation were 13.0, 10.6, 7.0, and 5.1ton ha^{-1}, respectively.

Differences among species and cultivars have been found under irrigation and dryland systems (Cash, 2005a,b; Cash et al., 2005a), but response to different water levels has not been tested in Montana. In Utah, grasses (Waldron et al., 2002) and grass cultivars within species (Jensen et al., 2001) respond differently to irrigation levels, which has important implications to provide a stable source of forages throughout the grazing season, especially when water availability is limited. Forage quality can also vary among irrigation levels (Asay et al., 2001; Jensen et al., 2002). The decline in forage production of sainfoin and alfalfa across different water levels was relatively small, suggesting tolerance to dry conditions for both crops (Peel et al., 2004).

Soil moisture varies widely among years and sites, but typically during April and May moisture is adequate for pasture seeding in western Montana (D. Cash, personal communication, 2005). After June, moisture and high temperatures limit success of forage seedlings unless irrigation water is available. A minimum of 60-cm of moist soil (approximately 10-cm of precipitation) is recommended for spring seeding (Holzworth et al., 2003). Drought-tolerant cultivars could improve results of sod-seeding by using cultivars with higher water-use efficiency, although they need water for establishment. Alfalfa germplasm have differences in water-use efficiency (Johnson and Rumbaugh, 1995; Ray et al., 1998). However new cultivars for the northern Great Plains have not been developed newer.

To overcome soil moisture limitations, timing of chemical application becomes relevant. Delaying sod-seeding date can improve sod control, but moisture becomes more limiting. Increasing soil water level by irrigation during establishment could enhance seedling development and yield the first year, but moisture level and its interaction with timing of glyphosate are not well understood. As stated previously, the importance of moisture conditions at the time of seeding is related to plant population and yield. However none of these factors have been evaluated under no-till seeding of alfalfa in Montana.

Economic Aspect of No-till Forages

No-till forage planting systems are less time-consuming and expensive than conventional planting methods. In Wyoming, conventional till vs. no-till forages were evaluated in relation to fuel and labor requirements (Koch, 1991). Alfalfa was no-till seeded (into bromegrass sod) with about 9.3 L of fuel and 2.5 hr of labor per hectare. The conventional tillage method of seeding required 140 to 150 L of fuel and 7 to over 15 hr of labor per hectare. No-till requires fairly inexpensive application of no-till forage drills, but these are not widely available.

There is no information available related to cost of forage production in no-till in Montana (Duane Griffith, personal communication, 2005). Cuomo et al. (1999) indicate that renovation of a cool-season pasture in Minnesota with alfalfa is an effective way of increasing forage production throughout the growing season and the cost of an additional ton of forage cost between \$8.1 and \$12.8, or about 10% of the cost of purchasing the extra forage as hay.

In general, studies have shown that the biomass of existing vegetation, timing of herbicide application and soil water content are key factors in successful establishment of no-till alfalfa. In rainfed conditions, no-till seeding success is dependent on timely and adequate precipitation. Therefore controlling soil water content after seeding could improve the establishment of recently planted seeds and yield during the establishment year.

Combined effects of the timing of sod suppression and water soil level during no-till establishment of alfalfa have not been studied in western Montana. In addition, no-till grasses, alfalfa and other legumes may be powerful options to encourage no-till forage seedings.

The goal of this research was to evaluate forage no-till techniques that could enhance yield of hayfields or pastures in Montana.

The specific objectives of this research were to:

1) evaluate the efficacy of glyphosate herbicide applied at different timings for sod control in no-till alfalfa in the spring,
2) compare the performance of RRA and a conventional alfalfa cultivar under different herbicide timings for sod control,
3) evaluate the effects of differential irrigation levels on alfalfa yield, and
4) evaluate grasses and legumes using no-till and conventional tillage techniques.

EXPERIMENT 1: NO-TILL ALFALFA

Material and Methods

Study Site

Experiments were conducted during 2004 and 2005, at the Montana State University (MSU), Livestock, Teaching & Research Center (45^{o} 39'N, 111^{o} 05'W; elevation 1350 m). The soil at the study site is classified as Meadowcreek loam series, with 0 to 4% slope (USDA-NRCS, 2002). The resident vegetation consisted of a 10-yr old alfalfa stand with a large component of Kentucky bluegrass, smooth bromegrass, dandelion (*Taraxacum officinale* Dhudhal), orchardgrass, meadow foxtail (*Alopecurus pratensis* L.) and quackgrass. Precipitation and temperatures data were retrieved from the MSU recording weather station, two kilometers from the study site. Thirty year (1971-2000) average precipitation at the site is 491 mm (Western Regional Climate Center, 2005).

Experimental Design

The 2004 and 2005 experiments were each established as a randomized complete block design with a modified split-plot arrangement of treatments. Main plots consisted of a 4 x 2 factorial arrangement of four planting methods (PM) and two alfalfa cultivars (CV). Each main plot was 45 m^2 (3 x 15 m). The PM were three herbicide application dates before no-till planting: four weeks prior to planting (NT4), two weeks prior to planting (NT2) and spraying and planting on the same day (NT0). Additionally, a conventional-tilled seedbed planting system (CONV) was included.

Alfalfa cv. Shaw is a Class 3 fall dormancy released by the Montana Agricultural Experimental Station (Ditterline et al., 2001). An experimental line, 'RROIBG-148' a glyphosate-tolerant or 'Roundup Ready alfalfa™[a] (RRA) was supplied by Forage Genetics International, Nampa, Idaho. The appropriate USDA compliance protocols for RRA were in effect.

Three control treatments were included in 2004 and 2005: 1) undisturbed vegetation for evaluation of the existing undisturbed forage vegetation of the site (CU), 2) the existing pasture after one initial glyphosate application on the same date as NT4 but without planting (CH) and 3) NT0-RRAG equivalent to NT0-RRA, except all weed control was performed with glyphosate.

Sod Control and Planting

In 2004, Roundup Ultra Max™ (glyphosate at 4.7 kg a.i. ha^{-1} in 190 L ha^{-1} of water) and ammonium sulphate (1.8 kg ha^{-1}) were sprayed for sod control in NT4 and CH (15 April 2004), NT2 (29 April 2004), and NT0 and NT0-RRAG on 15 May 2004. In 2005, glyphosate (6.0 kg a.i. ha^{-1} in 270 L ha^{-1} of water) was sprayed for sod control in NT4 (23 April 2005), NT2 (6 May 2005), and NT0 on 21 May 2005. A tractor sprayer was used for NT4 in the 2004 experiment, and a backpack sprayer for further applications, were used to apply the glyphosate and other herbicides. To simulate a conventional seedbed (CONV) in the 2004 experiment, a 2.5-cm depth of sod was removed two weeks before tilling (rototilled nine passes to 15 cm deep). In 2005, CONV plots were rototilled (five passes) in the fall (14 Sep. 2004) and one week before planting.

On 15 May 2004 Shaw and RRA were seeded 12.9 [72 pure live seed (PLS) m^{-1} row] and 13.8 (80 PLS m^{-1} row) kg PLS ha^{-1}, respectively. In 2005, Shaw and RRA were seeded 11.7 (75 PLS m^{-1} row) and 10.9 (74 PLS m^{-1} row) kg PLS ha^{-1}, respectively. The drill was a Truax™

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[a] Mention of a proprietary product name is for identification purposes only and does not imply endorsement or warranty to the exclusion of other products.

rangeland no-till drill (Truax Company Inc., New Hope, MN; http://www.truaxcomp.com). This drill has heavy single coulters in front to slice and open the soil surface, followed in tandem with double disc openers and individual packers in the back for each of the seven rows (20-cm row spacing). No fertilizer was applied at planting.

Pre-treatment Measurements

Pre-trial biomass (clipping at ground level), and species composition (hand separation) were obtained at each date of herbicide application from four randomly placed 1 m^2 quadrats. All samples were oven dried for one week at 42 ^oC and weighed.

Gravimetric soil water content was measured at 0-15, 15-30 and 30-60 cm the day of planting. The samples were oven-dried for a week at 42 ^oC to estimate gravimetric soil water content by weight difference for each whole plot. Soil chemical analyses (Midwest Laboratories, Inc., Omaha, NE) for pH, P (weak bray), K, Mg, Ca and OM were completed for 0-15 cm sampling depth for no-till plots and conventional plots in 2004.

Weed and Insect Control

For broadleaf and grass weed control in 2004, NT4, NT2, and CONV were treated six weeks after planting with a combination of Pursuit^{TM} {imazethapyr [2-[4.5-dihydro-4-methyl-4-(1 -methylethyl)-5-oxo-lH-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid]} at 0.44 L ha^{-1} and Poast Plus^{TM} {sethoxydim [2-[1-(ethoxyimino)butyl] 5-[2-(ethylthio)propo]-3-hydroxy-2-cyclohexen-1-one]} at 2.91 L ha^{-1} with a non-ionic surfactant (0.45 L ha^{-1}) and ammonium sulphate (1.8 kg ha^{-1}) in 190 L ha^{-1} of water. Eight weeks after planting NT0 was sprayed with the previously described herbicide and NT0-RRAG was sprayed with glyphosate at 2.35 kg a.i. ha^{-1} and ammonium sulphate (1.8 kg ha^{-1}). No post planting weed control was done in CH. No post emergence weed control was performed in the 2005 experiment.

A liquid insecticide, Furadan™ (carbofuran) [2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethyl carbamate] was sprayed at 0.36 L a.i. ha^{-1} in 190 L ha^{-1} of water on the experimental area on 3 June 2004 (19 days after planting, DAP) to control a severe infestation of alfalfa weevil (*Hypera postica* Gyllenhall) feeding on alfalfa seedlings. In 2005, Furadan10G™ , granular carbofuran was applied with the drill at planting at 1.2 kg a.i. ha^{-1}.

Irrigation

A subplot irrigation gradient was applied across the trials consisting of five water levels (WL). The water levels were applied by a line-source irrigation system (Hanks et al., 1976) in a non-random systematic arrangement. This system delivers a gradient of water application perpendicular to the line, so that high water level subplots (WL5) were located adjacent to the line and low water level subplots (WL1: rainfed) were located most distant from the line (Hanks et al., 1980). In 2004, each water level subplot was 4 m^2 (2.5 by 1.6 m), and spaced at 2.5-m and intervals from the line source sprinkler. The design was replicated four times, twice on each side of the line-source irrigation system in both 2004 and 2005 experiments.

The irrigation system had 16 sprinklers (Toro 2001™ series; The Toro Company Inc., Bloomington, MN; http://www.toro.com) with nozzles (setting 6) spaced at 6.1 m. The sprinklers were placed on 0.6-m high risers attached to a 7.6-cm diameter quick-coupling portable aluminum supply line. The system was operated at about four to five bars (400-500 kPa) and produced a wetted radius of approximately 15 m. Irrigation was applied once or twice weekly to provide 100% of local evapotranspiration data for alfalfa (U.S. Department of the Interior-Bureau of Land Reclamation, 2004) on the fully irrigated subplot (WL5). Irrigation was performed between 21 June 2004 and 4 Sep. 2004 for the 2004 experiment and from 21 June 2005 to 6 July 2005 in 2005 experiment.

Plastic rain gauges (8.5 cm diameter) were placed perpendicular to the irrigation system at 2.5-m intervals to record the water applied for each irrigation level in two sets per block. The WL1 treatment received natural precipitation and a very low level of irrigation. A 0.5-m border area was not sampled in the water level subplots to avoid border effects.

Plant Population and Yield Data Collection

Alfalfa populations were measured on 2 June 2004 (18 DAP) and 20 June 2004 (36 DAP) by counting the plants in two 1-meter segment of row selected randomly within each subplot. During the first count, percentage of seedlings damaged by insects was measured but in the second counting, after insect control, only plant populations were determined. In the 2005 experiment, stand counts were performed on 16 June 2005 (27 DAP).

In the 2004 and 2005 experiments, stand density (occupancy) were evaluated on 17 July 2004 (63 DAP) and 01 July 2005 (41 DAP), respectively by determining the percent of 5-cm row segments (50 spaces per subplot) that contained one or more seedlings to check irrigation effect on establishment. Forage yield was estimated in the 2004 trial only. It was measured by hand-clipping one quadrat of 1 m^2 to a 4-cm height on 28 July 2004 (harvest 1), 8 October 2004 (harvest 2) and one quadrat of 0.5 m^2 to a 4-cm height on 19 June 2005. The CU treatment had an additional harvest on 6 July 2004. No measurements were taken in the 0.20-m border of the plots to reduce border effects. Forage material was weighed in the field and two sub-samples (about 200 g) taken from each subplot. One sample was hand-separated into alfalfa, grasses and broadleaves weeds and oven dried with the other sample for a week at 42 ^{o}C and reweighed for dry matter determinations.

Data Analyses

Data were subjected to analysis of variance with the GLM procedure (SAS Inst., 2002). Individual subplots (n=220) were the experimental units. Parameters with excessive deviation from normality (PROC UNIVARIATE NORMAL procedure, SAS Inst., 2002) or non homogeneous variance transformation after testing the appropriate power transformation on the basis of an empirical relationship between the standard deviation and the mean (Kuehl, 2000). Non-transformed data are presented in tables and figures. To test treatments with controls, a one-way ANOVA that included single treatments and controls was performed. To compare the effect of weed control after emergence in NT0 (NT0-RRA vs. NT0-RRAG), one block was eliminated because alfalfa plant populations were very low in both treatments.

Mean separations were conducted with Fisher's protected least significant difference (LSD) at the 0.05 level of probability. Irrigation response was examined by testing linear, quadratic, cubic and quartic regressions of yield across water levels for each treatment using orthogonal polynomials contrast with unequal intervals (Gomez and Gomez, 1984) when interaction with WL were significant ($P<0.05$). Amounts of water applied by plots during the growing season were used in the computation of the coefficients. Single degree of freedom contrasts were used to conduct preplanned comparisons between treatments.

Results

Crop Growing Conditions

The weather conditions for the study period are summarized in Table 1. Precipitation during the first (Apr.-July) and second (Aug.-Sep.) harvest periods was similar to the 30-yr average, although warmer in March-Apr. During fall 2004 and winter 2005 temperatures were in general warmer than average and in the spring 2005 T Max temperatures were colder and precipitation in May was especially low with respect to the average, although 63% of May precipitation fell three days before and two days after planting the 2005 experiment.

Table 1. Summary of monthly precipitation and average maximum (T Max) and minimum (T Min) air temperature for year 2004 and 2005 (through July) and the 30-year means (1971-2000) at Bozeman, MT†.

	Precipitation (mm)			Mean T Max (°C)			Mean T Min (°C)		
Month	30-yr	2004	2005	30-yr	2004	2005	30-yr	2004	2005
January	21	20	6	0.9	1.5	0.1	-10.0	-11.4	-10.1
February	20	33	8	3.8	3.5	6.6	-7.6	-8.3	-6.4
March	35	19	25	8.1	12.7	8.5	-4.2	-2.7	-3.2
April	53	51	62	13.1	16.0	12.1	-0.3	-0.2	-0.1
May	77	80	28	18.0	16.8	16.2	4.1	3.7	3.7
June	74	74	70	23.1	21.8	19.7	7.9	6.8	7.6
July	38	42	27	27.6	28.0	27.5	10.9	10.7	9.8
August	38	35	-	27.3	26.4	-	10.3	9.1	-
September	46	42	-	21.7	20.7	-	5.6	4.4	-
October	40	45	-	14.8	15.2	-	0.6	0.3	-
November	28	15	-	5.1	7.6	-	-5.7	-5.2	-
December	22	15	-	1.1	4.7	-	-9.7	-6.3	-
Annual	*491*	*471*	-	*13.8*	*14.6*	-	*0.2*	*0.1*	-

† Montana State University, Bozeman, MT (45°40'N Lat., 111°03'W Long., 1474 m). Source: Western Regional Climate Center (2005).

Aboveground biomass (sod) varied among spraying dates with the greatest biomass at NT0 (Table 2). The sod composition was mostly grasses (smooth bromegrass, Kentucky bluegrass) in NT4 and broadleaves (dandelions) in NT2 and NT0. In the 2005 experiment, sod growth was in general slower but specially in alfalfa, without large differences among the other components.

Data indicated that fertility levels (Table 3) at planting in CONV and no-till plots were adequate for alfalfa establishment and production (Jacobsen et al., 2003).

Table 2. Sod biomass (dry matter basis) and sod composition (as % total biomass) at three herbicide application dates prior to planting[†].

Planting method (PM)	Sod biomass	Alfalfa[‡]	Weeds: Grass	Weeds: Broadleaf	Dead material
	kg DM ha^{-1}	%	%	%	%
	2004				
NT4	870	13	42	9	36
NT2	1590	7	29	50	14
NT0	2560	17	28	45	9
	2005				
NT4	233	2	23	13	62
NT2	642	21	28	27	24
NT0	2060	3	39	58	0

[†] Planting dates: 15 May 2004 and 21 May 2005.
[‡] Old alfalfa present at a density of 3 ±1 crowns m^{-2} in 2004 and 2 ±1 in the 2005 experiment sites.
NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

Table 3. Chemical soil analyses of the surface soil (0-15 cm) before planting, 2004.

Planting method (PM)	OM	NO_3-N	P	K	Mg	Ca	CEC	pH
	%	ppm	ppm	ppm	ppm	ppm	meq 100 gr^{-1}	
CONV[†]	4.3	7	22	332	819	2,310	19.2	7.2
NT[‡]	4.9	3	41	489	705	2,368	19.0	7.3

OM: Organic matter; CEC: Cation exchange capacity.
[†] CONV: Conventional. A 2.5-cm sod was removed and tillage occurred 7 days before planting.
[‡] Samples were composited randomly across blocks of NT treatments**.**

Alfalfa Establishment

2004 Experiment. Topsoil water contents (0-15 and 15-30 cm) at planting were different among planting methods (P<0.001; Table 4). No differences were observed between CONV and NT4. On average, treatments CONV and NT4 had 22% and 39% more water content in the 0-15 cm zone at planting than NT2 and NT0, respectively. Competition for light and water from resident vegetation in NT2 and NT0 were likely more severe compared to NT4, due to large differences in standing biomass at timing of spraying (Table 2).

Table 4. Gravimetric soil water content at planting in 2004 and 2005 experiments†.

Planting method (PM)	Soil depth (cm) 0 – 15	15 – 30	30 – 60
	% dry weight		
	2004		
CONV	20.5 a‡	22.3 a	24.5
NT4	20.9 a	21.3 a	23.4
NT2	17.0 b	16.3 b	23.6
NT0	14.9 c	15.2 b	21.7
	2005		
CONV	26.8 b	22.1	24.3
NT4	29.4 a	23.2	24.0
NT2	29.3 a	23.3	23.9
NT0	27.4 b	19.5	22.8

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.
† Planting: 15 May 2004 and 21 May 2005.
‡ Means sharing a different letter vertically (a,b,c) within a year are different at the 5% level of significance based on Fisher's protected LSD test.

Damage from insects was observed in the first counting of plants and the proportion of damaged seedlings differed among planting method (P<0.005), with 52, 37 and 15% damaged plants in NT4, NT2 and CONV (data not shown). No difference in insect damage between NT4 and NT2 was found. NT0 was not considered in this analysis due to extremely low plant populations, however dead seedlings were not found. After all treatments were sprayed with carbofuran, plant stands were determined at 35 DAP to reevaluate establishment. Significant effects for plant population 35 DAP were found for planting methods (P<0.001). The PM x CV interaction was not significant (P>0.05; Table 5). Plant population was similar between CONV and NT4, but NT2 had 55% fewer plants than CONV and NT4. Emergence in NT0 was very low (≤ 6 plants m^{-1} row) compared to the other treatments. Occupancy measured 63 DAP had a similar relation among planting methods to plant population (P<0.001). Occupancy increased in a quadratic response (P=0.041) with irrigation level. The PM x WL interaction was not significant (P>0.05). The differences between dryland (WL1) and full irrigated (WL5) treatment ranged from 5 to 10 percent occupancy.

The RRA had a significantly higher plant population (P=0.049) and occupancy (P<0.001) than Shaw (Table 5). The CV x WL interaction was not significant for occupancy (P=0.463). Insect damage was similar between cultivars (P=0.307).

2005 Experiment. Topsoil water content (0-15 cm depth) at planting, was different among planting methods (P=0.01; Table 4). On average, treatments NT2 and NT4 had 9 and 7% more soil water content at emergence than CONV and NT0, respectively.

Significant effects for plant population were found for planting methods (P<0.001) and cultivars (P=0.002) but their interaction was not significant (P=0.055; Table 6). Plant population was higher in CONV, and was similar between NT4 and NT2. NT0 was the poorest treatment with less than 2 plants m^{-1} row. Occupancy measured 41 DAP was different among planting methods (P<0.001) without significant PM x CV interaction (P>0.05), however differences among planting methods remain similar to the plant population. Occupancy did not vary with irrigation (P>0.05).

Insect damage was not evident in the 2005 experiment, but field observation done by Dr. Sue Blodgett from the MSU Animal & Range Sciences indicated that alfalfa weevil was causing damage in old alfalfa plants that were not killed by glyphosate. A complementary insecticide trial conducted adjacent to this experiment showed that the use of insecticide (in the spring) versus no insecticide significantly increased (P=0.02) the plant population in NT0-RRA from 1 to 2.5 plants m^{-1} row (Appendix A).

Table 5. Effect of planting methods and alfalfa cultivars on plant population and occupancy in the 2004 experiment.

Planting method (PM)	Plant population: 2 June 2004 (17 DAP)[†]			Plant population: 20 June 2004 (35 DAP)[†]			Occupancy 17 July 2004 (63 DAP)[§]		
	RRA	Shaw	Mean	RRA	Shaw	Mean	RRA	Shaw	Mean
	------------------ plants m^{-1} row ------------------						- % of 5-cm row spaces occupied -		
CONV	42	38	40a[‡]	29	26	28a	72	66	69a
NT4	38	34	36a	35	31	33a	75	71	73a
NT2	29	13	21b	24	4	14b	68	27	48b
NT0	10	4	7c	6	1	4c	24	6	15c
Mean	*30*	*22*		*24X*[‡]	*16Y*		*60X*	*42Y*	

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day. DAP: days after planting.

[†] There was not a significant irrigation effect.

[‡] Means sharing a different lowercase letter vertically (a,b,c) or a different uppercase letter horizontally (X,Y) by date are different at the 5% level of significance based on Fisher's protected LSD test.

[§] Values within water levels. The irrigation effect is included in these values; The response to water level was quadratic and the interactions with water levels were not significant (P>0.05).

RRA had significantly higher plant population (P=0.002) and occupancy (P<0.001) than Shaw (Table 6). The CV x WL interaction was not significant for occupancy (P=0.735). Occupancy was similar among planting methods between 2004 and 2005, but not in NT4.

Table 6. Effect of planting methods and alfalfa cultivars on plant population and occupancy in the 2005 experiment.

Planting method (PM)	Plant population† 19 Jun 2005 (27 DAP)			Occupancy 01 July 2005 (41 DAP)		
	RRA	Shaw	Mean	RRA	Shaw	Mean
	------------plants m^{-1} row------------			---% of 5-cm row spaces occupied---		
CONV	29	17	23a‡	83	51	67a
NT4	14	5	9b	41	25	33b
NT2	9	7	8b	42	34	38b
NT0	2	1	2c	9	4	7c
Mean	*13X*‡	*8Y*		*44X*	*29Y*	

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day. DAP: days after planting.
† There is no irrigation effect; the first irrigation began on 20 June 2005.
‡ Means sharing a different lowercase letter vertically (a,b,c,) or a different uppercase letter horizontally (X,Y) by plant population or occupancy are different at the 5% level of significance based on Fisher's protected LSD test.

Production in the Establishment Year, 2004

Alfalfa. The probability results from ANOVA for alfalfa, weeds and total biomass are presented in Table 7. For first harvest alfalfa yield, planting methods (PM) and the PM x CV interaction were significant sources of variation. Combined over water levels, production of RRA in CONV, NT4 and NT2 was similar and higher than NT0 (Table 8). For Shaw, NT4 had the highest yield followed by CONV, NT2 and NT0. The only planting method where cultivars had significantly different yields was in NT2 with higher yield in RRA than Shaw. NT0 in RRA and NT0 and NT2 in Shaw had very low production.

At the second harvest, planting method and the PM x CV interaction were significant sources of variation (Table 7). Combined over water levels in RRA, NT4 had the highest yield, followed by CONV, NT2 and NT0. Shaw had similar yields for CONV and NT4, but both were significantly higher than NT2 and NT0 (Table 8). The only planting methods where cultivars were significantly different was with CONV, with a higher yield for Shaw.

For total alfalfa yield, NT4 had the highest yield of alfalfa across water levels and cultivars. Differences were not significant between CONV and NT2. NT0 had the lowest yield.

Irrigation Effect on Alfalfa. Water received from irrigation during the first harvest period applied to WL1 through WL5, respectively, were 11, 45, 83, 148, and 225 mm; and 7, 24, 49, 105, and 178 mm during the second harvest.

Alfalfa yields in the first harvest had a significant quadratic trend and the PM x WL interaction was significant (Table 7). After testing trend analysis individually for water levels by planting method NT4 responded to a significant quadratic trend (P<0.001) but CONV and NT2 had a linear response (P<0.001; Fig. 1). NT0 yields were poor and did not have a significant trend across water levels. For the second harvest the general response to water levels was quadratic, without significant interactions (Table 7; Fig. 2).

Total alfalfa yield had a significant quadratic trend but significant linear interaction deviation (PM x WL linear), although the global test for PM x WL interaction was not significant. The partititioning of sums of squares for interaction sometimes can reveal certain interactions (Kuehl, 2000), therefore trend analysis were conducted individually by planting method. The NT4 quadratic response was significant (P<0.001), but NT2 and CONV had linear responses (P=0.004, P<0.001; Fig. 3). NT0 had the lowest yield and did not respond to irrigation.

Table 7. *P*-values of F-tests from ANOVA and orthogonal polynomial regression partitions for water level factor of four planting methods and two alfalfa cultivars at five water levels during the establishment year, 2004 experiment.

		Alfalfa			Weeds[†]			Biomass		
Source of variation	df	Harv. 1[‡]	Harv. 2	Total	Harv. 1	Harv. 2	Total	Harv. 1	Harv. 2	Total
		---------- *P*-value ----------								
Planting method (PM)	3	<0.001	<0.001	<0.001	<0.001	<0.001	0.009	<0.001	<0.001	<0.001
Cultivar (CV)	1	0.289	0.747	0.750	0.391	0.003	0.006	0.486	0.179	0.701
PM x CV	3	0.025	0.047	0.060	0.618	0.028	0.139	0.040	0.080	0.134
Water levels (WL)[§]	4	<0.001	0.054	<0.001	0.525	0.005	0.013	<0.001	<0.001	<0.001
WL linear	1	<0.001	0.033	<0.001	0.943	<0.001	0.003	<0.001	<0.001	<0.001
WL quadratic	1	0.001	0.029	0.002	0.142	0.763	0.198	0.053	0.040	0.005
WL cubic	1	0.849	0.934	0.149	0.322	0.286	0.130	0.554	0.544	0.545
WL quartic	1	0.940	0.757	0.505	0.877	0.840	0.784	0.989	0.681	0.844
PM x WL	12	0.011	0.847	0.191	0.186	0.006	0.013	0.072	0.926	0.689
PM x WL linear	3	0.002	0.387	0.020	0.006	0.007	<0.001	0.048	0.995	0.420
PM x WL quadratic	3	0.112	0.477	0.173	0.900	0.823	0.881	0.094	0.703	0.189
PM x WL cubic	3	0.453	0.680	0.594	0.766	0.029	0.430	0.566	0.904	0.855
M x WL quartic	3	0.857	0.887	0.967	0.653	0.119	0.239	0.623	0.284	0.710
CV x WL	4	0.280	0.590	0.963	0.072	0.030	0.001	0.541	0.187	0.870
PM x CV x WL	12	0.068	0.989	0.816	0.871	0.613	0.894	0.018	0.939	0.883

[†] Harv (Harvest) 1: 28 July 2004; Harv. 2: 08 Oct. 2004.

[‡] Total of broadleaf grasses and grassy weeds.

[§] A valid error term is not available to test the main effect of water levels, because that effect is not randomized (Hanks et al., 1980).

Table 8. Alfalfa production by harvest across water levels within planting methods and cultivars during establishment year, 2004 experiment.

Planting method (PM)	Harvest 1 (28 July 2004)		Harvest 2 (08 Oct. 2004)		Total‡
	RRA	Shaw	RRA	Shaw	
	-------------------	-------------------	kg DM ha^{-1}	-------------------	-------------------
CONV	1322a†	1384b	898bX	1831aY	2717b
NT4	1761a	2112a	2020a	1972a	3933a
NT2	1270aY‡	365cX	1398b	1000b	2017b
NT0	123b	18c	554b	290c	493c

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

†Means sharing a different lowercase letter (a,b,c,d) within a column or a different uppercase letter horizontally (X,Y) between cultivars are different at the 5% level of significance based on Fisher's protected LSD test.

‡ Data averaged across water levels and cultivars only in total.

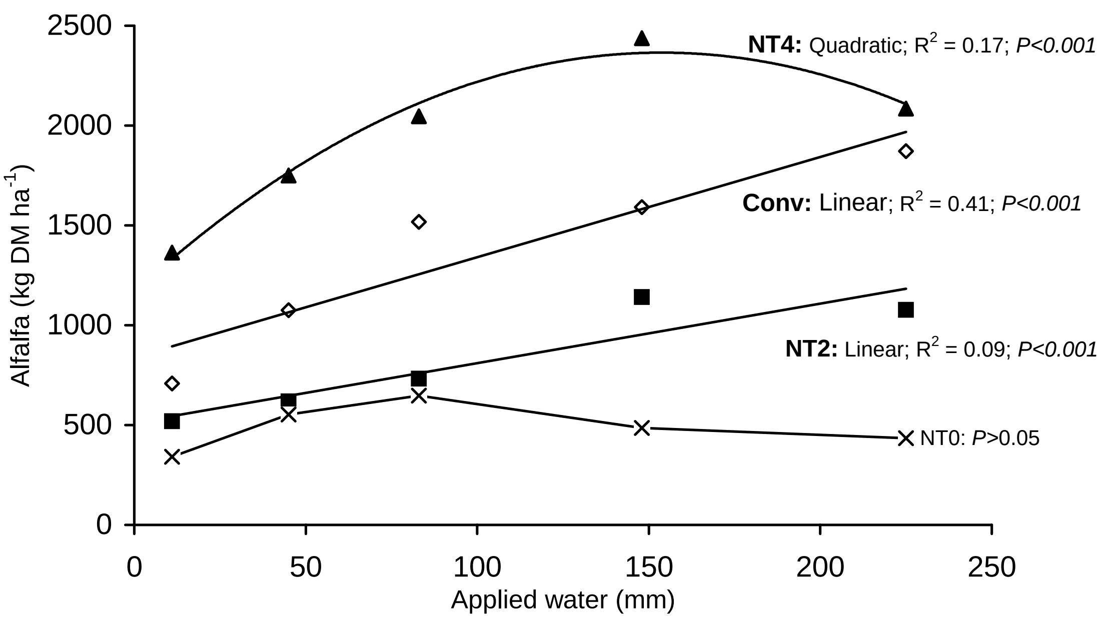


Fig. 1. First harvest alfalfa yield trends of four planting methods across cultivars at five water levels, year 2004. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

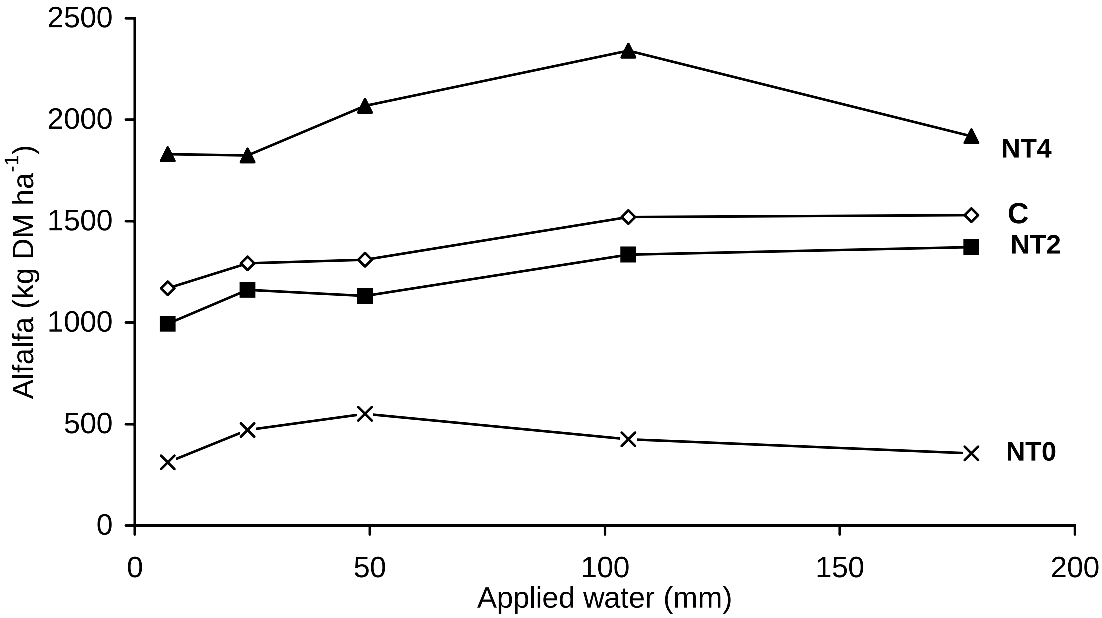


Fig. 2. Second harvest alfalfa yield trends of four planting methods across cultivars at five water levels, year 2004. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

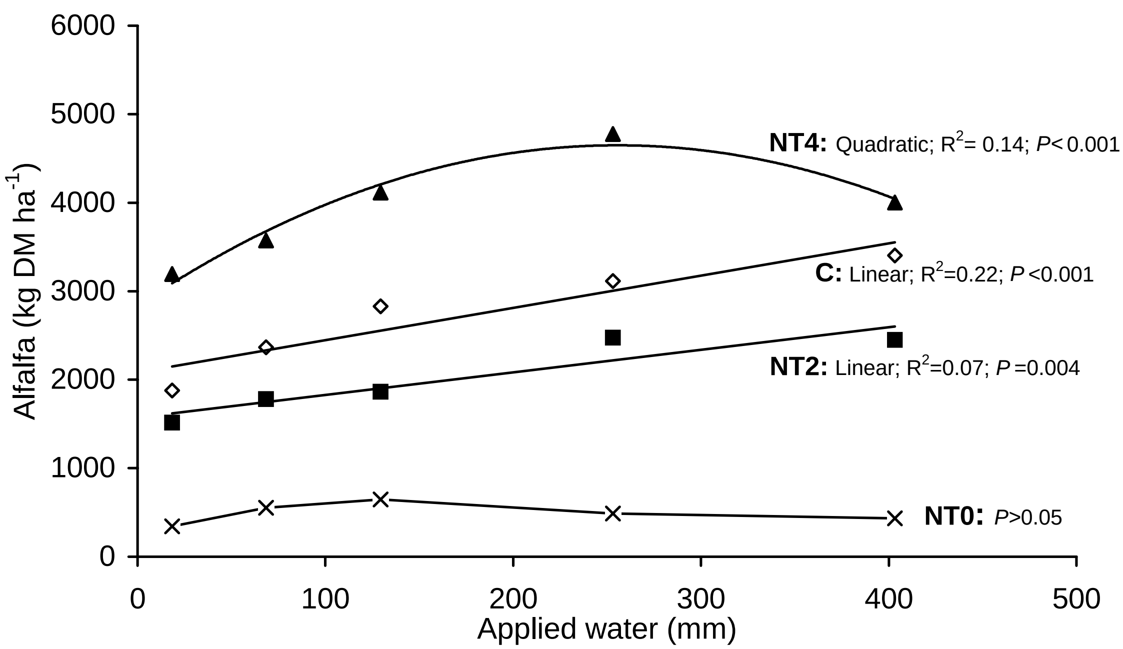


Fig. 3. Total alfalfa yield trends of four planting methods across cultivars at five water levels, year 2004. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

Weeds. In the first harvest, weed biomass was different among planting methods, but cultivars and PM x CV interaction were not significant sources of variation (Table 7). The highest weed biomass was in CONV. Differences among the other treatments were not significant (Table 9). Weed biomass did not present significant trends across water levels, however PM x WL linear interaction was significant. Individual trend analyses of planting methods indicate that CONV and NT0 had linear trends (P=0.009, P=0.04, respectively; Fig. 4a); non significant trends were observed in the other treatments.

For the second harvest in 2004, planting methods, cultivars, and the PM x CV interaction were significant sources of variation (Table 7). Combined over water levels, weed production in RRA was similar among CONV, NT4 and NT2 and all lower than NT0 (Table 9). For Shaw, the trend was similar but NT2 and NT0 had similar amount of weeds. NT2 was the only planting method where Shaw had more weed biomass than RRA.

Table 9. Total weed production across water levels and cultivars within planting methods and harvest during establishment year, 2004 experiment.

		Harvest 2		
Planting method (PM)	Harvest 1[†‡]	RRA	Shaw	Total[‡]
	------------------	kg DM ha^{-1}	------------------	
CONV	475a[§]	462b	475b	943a
NT4	164b	379b	461b	584c
NT2	94b	433bX[§]	850aY	736bc
NT0	99b	635a	755a	794ab

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and seeding at the same day.
[†] Harvest 1: 28 July 2004; Harvest 2: 08 October 2004.
[‡] Data averaged across water levels and cultivars.
[§] Means sharing a different lowercase letter vertically (a,b,c,d) within a column or a different uppercase letter horizontally (X,Y) between cultivars are different at the 5% level of significance based on Fisher's protected LSD test.

In general weeds presented a linear trend across water levels but PM x WL interaction was significant. Therefore trends across water levels were different among planting methods and

NT4 showed a cubic trend (P=0.038) and NT0 a linear trend (P<0.001) without significant trends in the other treatments (Fig. 4b). Across planting methods, Shaw had more weed biomass than RRA in WL4 and WL5 but similar in the other water levels.

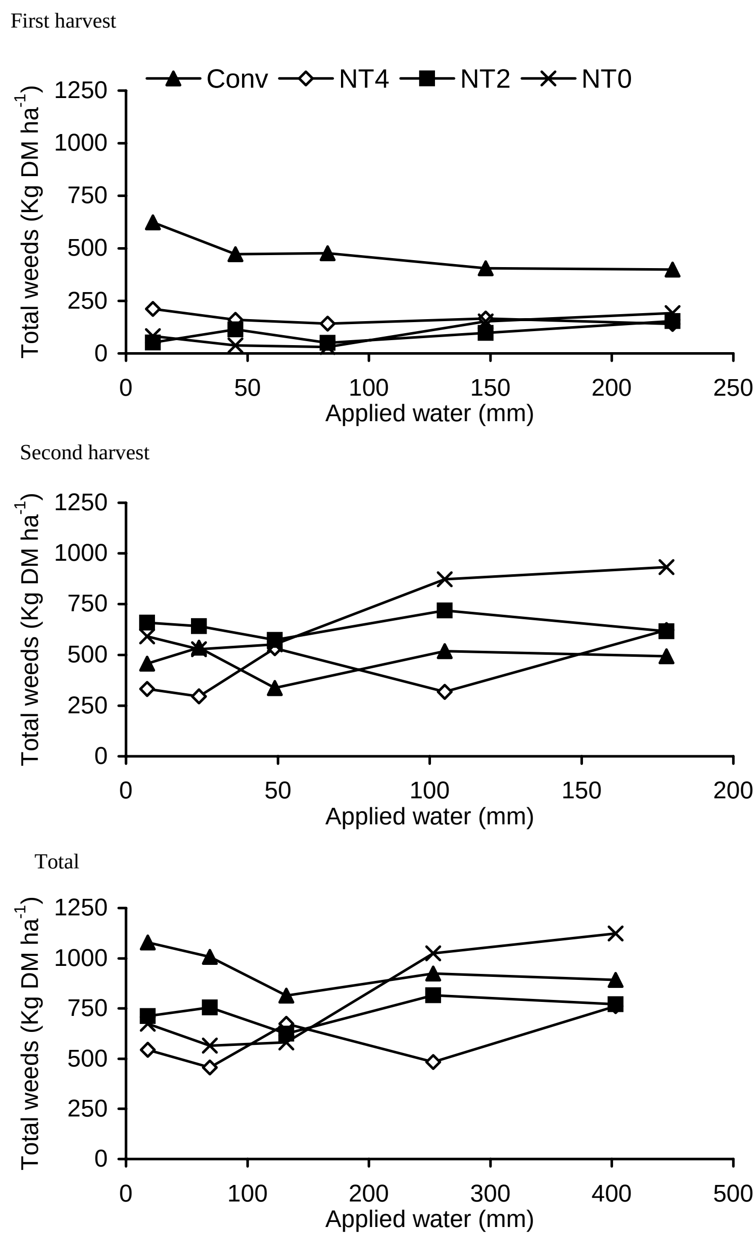


Fig. 4. Total weed biomass yield trend of four planting methods across cultivars at five water levels, year 2004. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and seeding on the same day.

For total weed biomass, planting methods, cultivars, PM x WL and CV x WL were significant sources of variation (Table 7). NT0 was the only planting method with a significant and cubic trend (P=0.023; Fig. 4c) and CONV was the planting method that had more weed biomass in WL1 and WL2. Likewise, second harvest Shaw had more weed biomass than RRA at WL4 and WL5.

Biomass Yield. In the first harvest, planting method, PM x CV and PM x CV x WL were significant sources of variation (Table 7). In RRA, NT4 had similar yield than CONV and NT2 and NT0 had lowest yield. In Shaw, biomass yield was similar between CONV and NT4 but different from NT2 and NT0 (Table 10). The only significant difference between cultivars was in NT2, with less yield in Shaw. In general, biomass yield presented a linear trend across water levels but PM x WL linear interaction was significant. Therefore trends across water levels were different among planting methods and NT4 showed a quadratic trend (P=0.006) and CONV as well as NT2 a linear trend (P<0.001).

Table 10. Biomass yield (alfalfa plus weeds) across water levels within planting methods and cultivars during establishment year, 2004 experiment.

	Harvest 1[†]			
Planting method (PM)	RRA	Shaw	Harvest 2[‡]	Total[‡]
	---------- kg DM ha^{-1} ----------			
CONV	1807a[§]	1849a	1832b	3661b
NT4	1910a	2291a	2416a	4517a
NT2	1359aY[§]	464bX	1841b	2753b
NT0	148b	192b	1117c	1287c

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.
[†] Data presented only as reference (Interaction PM x CV x WL was significant, P=0.017).
[‡] Data averaged across water levels and cultivars only in harvest 2 and total.
[§] Means sharing a different lowercase letter vertically (a,b,c) within a column or a different uppercase letter horizontally (X, Y) between cultivars are different at the 5% level of significance based on Fisher's protected LSD test.

The statistical results were similar between the second harvest and biomass production (Table 7 and 10). The highest biomass yield was reached by NT4, without differences between CONV and NT2 followed by NT0. The irrigation response was in general quadratic without any significant interactions (P>0.05; Fig. 5).

Comparison to Controls. The one-way ANOVA that included all treatments and controls (CU, CH, and NT0-RRAG) revealed that the maximum total biomass yield during establishment year was superior in CU to all treatments at all water levels (P<0.001), having a linear trend response to water levels (P=0.049; Fig. 5). The average alfalfa dry matter component in CU was 48% (varied from 41 to 57% among water levels). CU had less alfalfa than NT4 (85%) and NT2 (64%) but more than NT0 (36%).

The application of glyphosate alone over the sod without planting (CH) reduced alfalfa, broadleaf and grass weed biomass during the establishment year (P<0.05; Fig. 6) compared to CU. The proportion of alfalfa in the yield remained similar to CU (P=0.41), however the grass component of weeds decreased (P<0.001) and broadleaves increased (P<0.001; Fig. 6) in CH. Old alfalfa plants in NT4 were not killed, but their growth was delayed.

Comparison of Glyphosate and Conventional Herbicides on RRA. To compare the effect of glyphosate (NT0-RRAG) to a conventional herbicide mix (NT0-RRA) after emergence one block was removed from the ANOVA because plant population was very low. NT0-RRAG had higher alfalfa, less weed biomass and higher total biomass yield than NT0-RRA (P<0.05). However, NT0-RRAG had less broadleaves weeds (P<0.001) and similar grasses content (P=0.259) compared to NT0-RRA (P<0.05; Fig. 7).

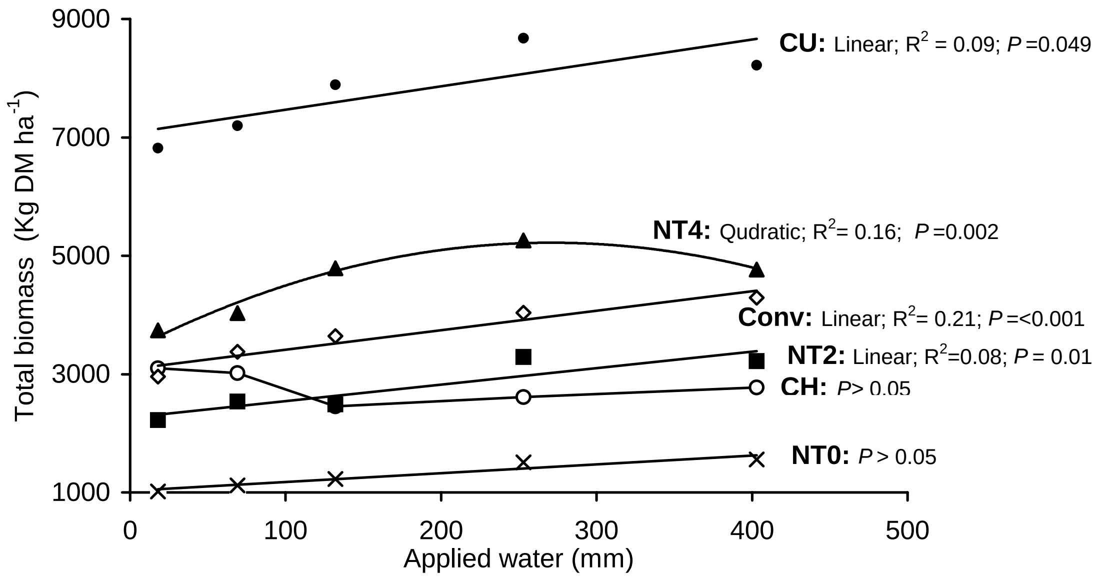


Fig. 5. Total biomass yield trends of four planting methods across cultivars and control treatments (CU and CH) at five water levels, year 2004. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day; CU: Control undisturbed; CH: Sprayed like NT4 but not planted.

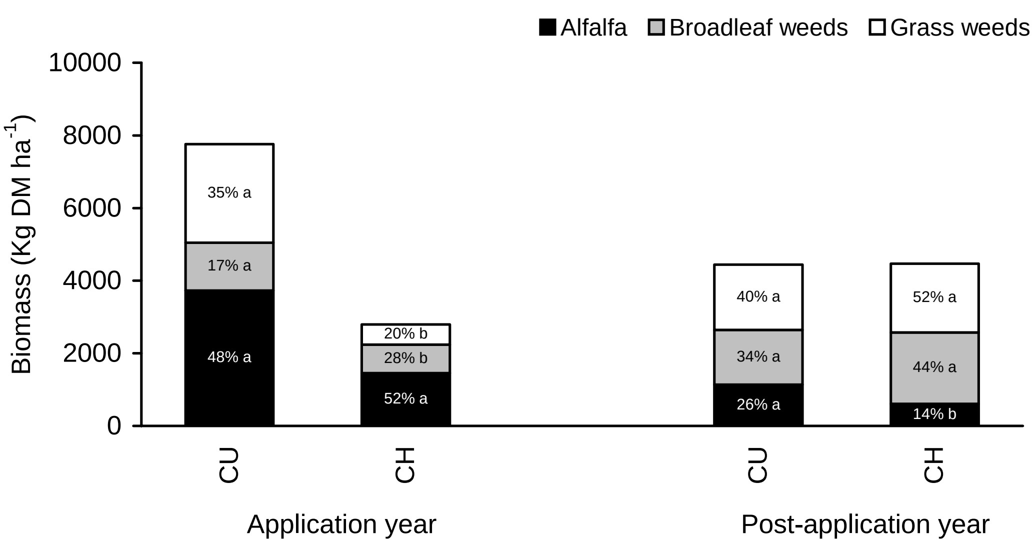


Fig. 6. Effect of glyphosate early in the spring on yield during application year and in the post-application year across five water levels. CU: Control undisturbed; CH: Sprayed like NT4 but not planted. Three harvest in CU and two harvests in CH during establishment year and one harvest in post-establishment year. Means with a different letter by weed component between CU and CH bars by component are different at the 5% level of significance based on Fisher's protected LSD test.

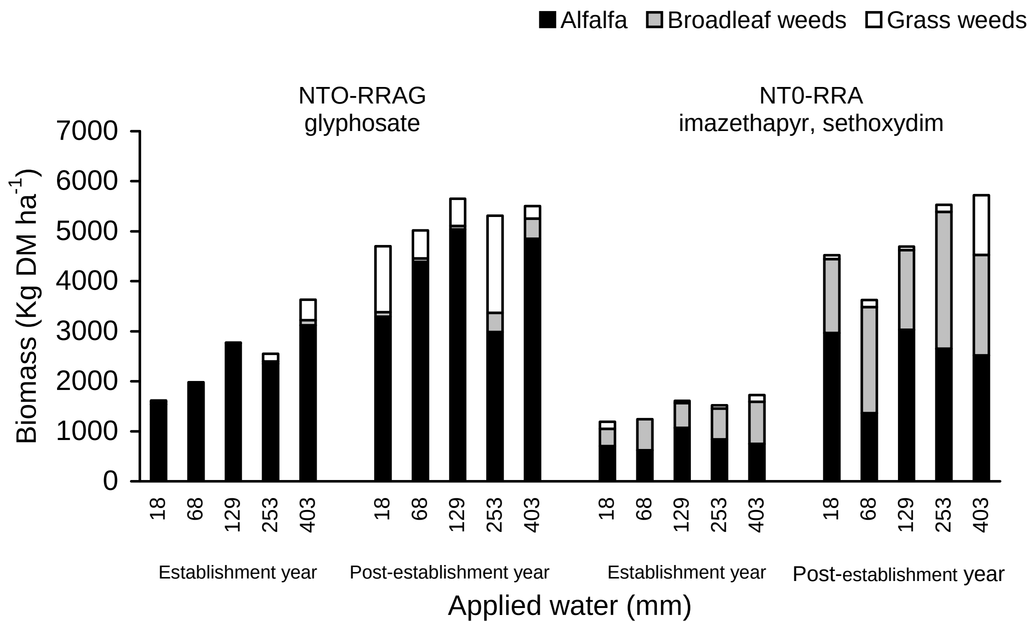


Fig. 7. Effect of postemergence chemical weed control in RRA with glyphosate (NT0-RRAG) and conventional herbicides: imazethapyr, sethoxydim (NT0-RRA) at five water levels in NT0, during establishment (2004) and post-establishment year (2005). Two harvests during establishment year and one harvest in post-establishment year. During post-establishment year irrigation was not performed. One block was eliminated in this analysis, because plant population was very low.

Production in the Post- Establishment Year, 2005

Alfalfa. The probability levels from ANOVA for alfalfa, weeds and total biomass yield are presented in table 11. The main effects of planting methods and cultivars were significant sources of variation without significant interactions with any other factor. Combined over water levels and cultivars, alfalfa yield was similar among CONV, NT4 and NT2 but all were significantly higher than NT0 (Table 12). Across planting methods and water levels yield of RRA was 60% higher than those of Shaw.

Weather conditions between Apr. and June 2005 were in general dryer (especially in

May) and colder than the 30-yr average data (Table 1). Irrigation effect was analyzed by orthogonal polynomial contrasts using the total amount of water supplied by irrigation during 2004 to develop the polynomial coefficients. Alfalfa yields had a significant linear response without significant PM x WL interaction. Therefore the response to irrigation was similar among planting methods (Fig. 8).

Table 11. *P*-values from F-tests from ANOVA and orthogonal polynomial regression partitions† for water level factor of four planting methods and two alfalfa cultivars at five water levels during year after establishment†, 2004 experiment.

Source of variation	df	Alfalfa	Weeds‡	Total
		---------------------------- *P*-value ----------------------------		
Planting method (PM)	3	<0.001	<0.002	0.027
Cultivar (CV)	1	0.002	0.016	0.028
PM x CV	3	0.178	0.417	0.417
Water levels (WL)§	4	0.029	0.331	0.187
WL linear	1	0.003	0.106	0.073
WL quadratic	1	0.585	0.561	0.965
WL cubic	1	0.317	0.313	0.993
WL quartic	1	0.543	0.427	0.085
PM x WL	12	0.398	0.211	0.783
PM x WL linear	3	0.348	0.100	0.198
PM x WL quadratic	3	0.857	0.235	0.844
PM x WL cubic	3	0.689	0.850	0.857
PM x WL quartic	3	0.084	0.332	0.422
CV x WL	4	0.150	0.871	0.079
PM x CV x WL	12	0.417	0.105	0.031

† Harvest date: 15 June 2005.
‡ Broadleaf and grassy weeds.
§ A valid error term is not available to test the main effect of water levels, because that effect is not randomized (Hanks et al., 1980).

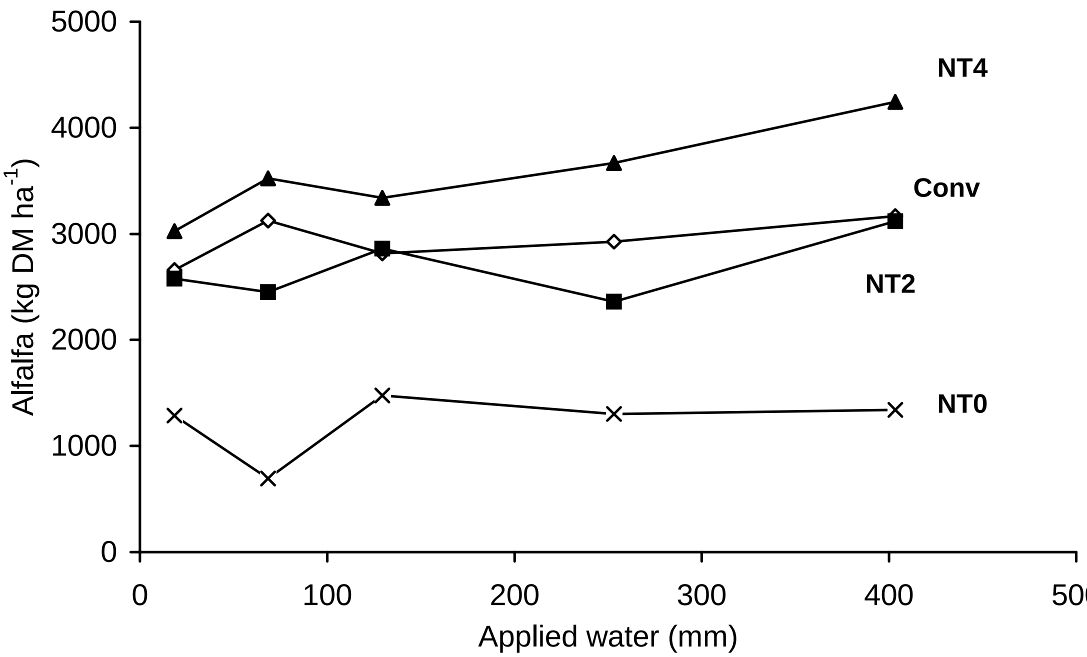


Fig. 8. Alfalfa yield trends of four planting methods across cultivars at five water levels, year 2005. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

Weeds. Weed biomass varied among planting methods with the lowest yield in NT4 and CONV and highest yield in NT0 and NT2 (Table 12). Weed contribution to total biomass yield increased in the no-till treatments from 27, 49 to 73% in NT4, NT2 and NT0, respectively. Weed content was 47% higher in Shaw than RRA. Weed biomass did not have a significant trend across water levels and the PM x WL interaction was not significant (Fig. 9).

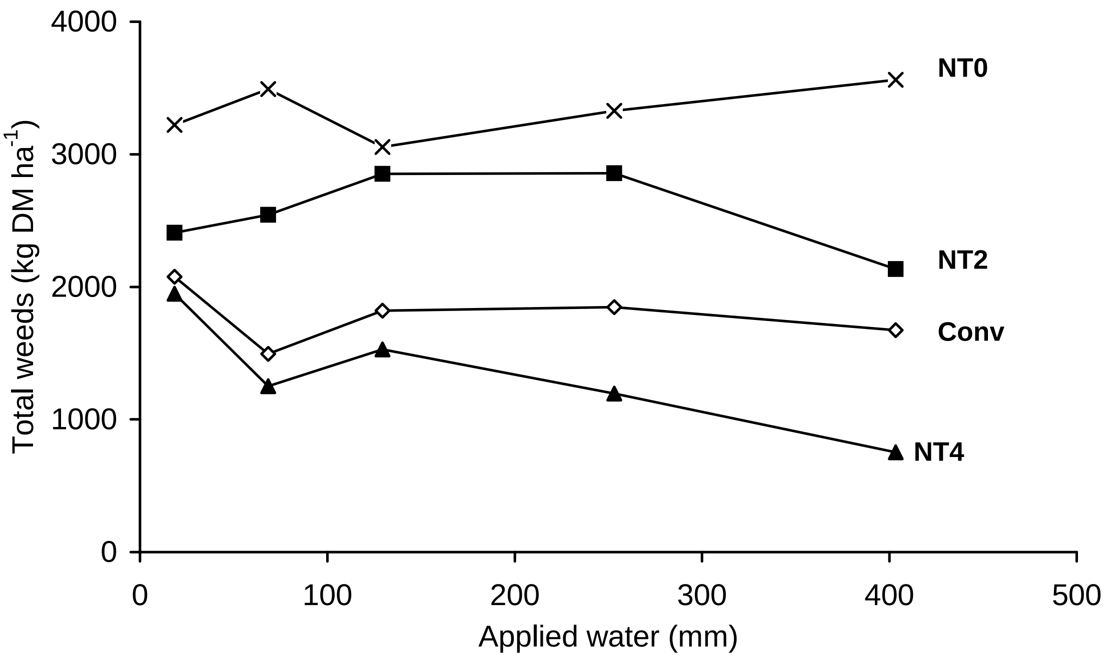


Fig. 9. Total weed biomass yield trends of four planting methods across cultivars at five water levels, year 2005. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

Biomass Yield. Planting methods, cultivars and PM x CV x WL were significant sources of variation (Table 11). NT4 and NT2 had the highest total biomass yield followed by CONV and NT0 (Table 12). Between cultivars, RRA had 8% more yield than Shaw. The total biomass yield did not respond to the previous years irrigation and trend analyses were not significant (Fig. 10).

Table 12. Forage yield across water levels within planting methods and cultivars during post establishment year[†], 2004 experiment.

Planting method (PM)	Yield								
	Alfalfa			Weeds[‡]			Total[§]		
	RRA	Shaw	Mean	RRA	Shaw	Mean	RRA	Shaw	Mean
	kg DM ha^{-1}								
CONV	2890	2987	2938a[¶]	1808	1757	1783bc	4698	4744	4721b
NT4	4242	2877	3559a	911	1760	1336c	5153	4637	4895ab
NT2	3543	1803	2673a	1846	3272	2559ab	5388	5075	5232a
NT0	2133	307	1220b	2737	3925	3332a	4870	4232	4551b
Mean	*3202X*[¶]	*1993Y*		*1826X*	*2679Y*		*5027X*	*4672Y*	

CONV: Sod control by tillage; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day.

[†] Harvest date: 19 June 2005.

[‡] Broadleaf and grassy weeds.

[§] Data presented only as reference (Interaction PM x CV x WL was significant, P=0.031).

[¶] Means sharing a different lowercase letter vertically (a,b,c) within a column or a different uppercase letter horizontally (X,Y) are different at the 5% level of significance based on Fisher’s protected LSD test.

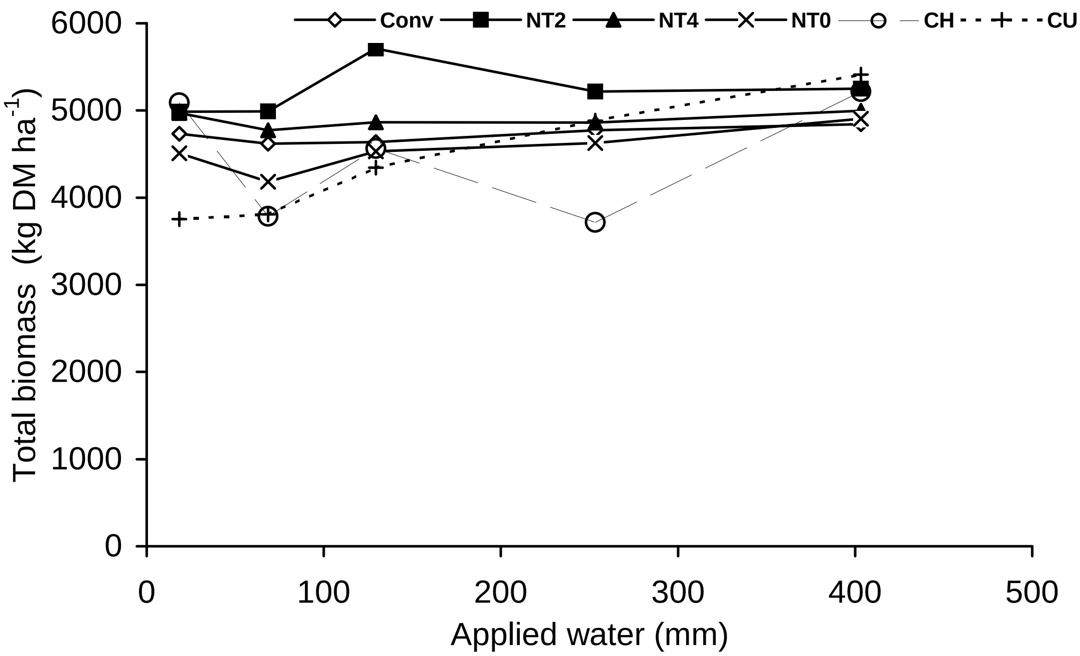


Fig. 10. Total biomass yield trends of four planting methods across cultivars and control treatments (CU and CH) at five water levels, year 2005. CONV: Conventional; NT4: No till sprayed 4 wk before planting; NT2: No till sprayed 2 wk before planting; NT0: No till spraying and planting on the same day; CU: Control undisturbed; CH: Sprayed like NT4 but not planted.

Comparison to Controls. The one-way ANOVA that included all treatments and controls (CU, CH, and NT0-RRAG) revealed that the maximum total biomass yield during the post-establishment year (2005) from CU was equal to all treatments at all water levels (P<0.05), with a linear trend response to water levels (P<0.001; Fig. 10). The alfalfa dry matter component in CU across water levels averaged 26%, which was less (P=0.035) than NT4 (72%) and NT2 (51%) but equal to NT0 (25%).

The application of glyphosate alone over the sod in 2004 without planting (CH) did not affect broadleaf and grassy weed biomass in the post-establishment year (P<0.05). The proportion of alfalfa in the yield decreased (P=0.012) from 26% in CU to 14% in CH, however the grass and broadleaf component remained similar (P=0.477, P=0.158; Fig. 6).

Comparison of Glyphosate and Conventional Herbicides on RRA. As in 2004, one block was removed from the ANOVA. NT0-RRAG had higher alfalfa, less weeds and equal total biomass yield compared to NT0-RRA (P<0.05). However, NT0-RRAG had less broadleaf weeds (P<0.001) and similar grasses content (P=0.153) compared to NT0-RRA (P<0.05; Fig. 7).

Discussion

Among no-till treatments, NT4 had the highest alfalfa populations followed by NT2 and NT0 during the establishment year in the 2004 experiment. NT4 had the highest soil water content and less biomass at herbicide application, which may indicate more available resources at establishment. The extent of water use and shading effect by resident vegetation in the 2004 experiment could have been less in NT4 compared to NT2 and NT0 due to early herbicide application, which should enhance conditions for alfalfa germination and emergence. Bowes and Zentner (1992) concluded that adequate soil water was the most important factor controlling the establishment of sod-seeded alfalfa in a low-yielding bluegrass sward in Saskatchewan. Suppressing resident vegetation with glyphosate increases light penetration, soil water content, soil temperature, enhanced alfalfa establishment and increased yield 3 to 10-fold compared to a non-sprayed area (Allen, 1994). The results from the 2004 experiment agree with those of Welty et al. (1981) who found that four weeks between herbicide application and planting was better than one, two or three weeks for alfalfa establishment and yield into an orchardgrass-bluegrass sod. In Nebraska, only 12 days were necessary to have a solid stand of alfalfa established in grass swards (Vogel et al., 1983). Tesar (1993) reported that alfalfa was re-established without significant autotoxicity if seedings were made at least two weeks after plowing or three weeks after glyphosate application on established alfalfa or after seeding failure. Therefore, sod biomass and soil water content are confounded with autotoxicity and allelopathy from other species but likely are affecting alfalfa establishment more in NT2 and NT0 than NT4 as reflected by plant population.

Conversely in the 2005 experiment, plant populations were in general lower and top-soil water content was on average 57% higher than the 2004 experiment. Differences in plant population and soil water content were not significant between NT4 and NT2. Although soil water content was higher in the 2005 experiment, temperatures were lower in April and May compared to 2004. This delayed sod growth in the 2005 experiment and potentially affected establishment. Moist soils warm more slowly than dry soils (Campbell and Norman, 1998). In contrast, Schellenberg and Waddington (1997) found great differences in establishment year of alfalfa in crested wheatgrass sod in three years when precipitation was plentiful during germination period. They proposed that other factors within plot microclimates prevented establishment, like evaporation from the soil surface, which decreased with amount of plant residue or soil disturbance. Taylor et al. (1969) reported that distribution of precipitation immediately following seeding was more important for germination and emergence of alfalfa sod-seeded into a Kentucky bluegrass than soil and air temperature in Lexington, KY. Therefore, low temperatures in early spring, high soil water content and less sod competition, made for large differences between the two years. Germination/establishment conditions in the 2005 experiment were less optimal affecting the no-till treatments more than CONV.

Irrigation slightly increased establishment in the 2004 experiment but not in the 2005 experiment. Plant populations in NT2, and especially in NT0, were very low. Low irrigation response in the 2005 experiment was likely related to the higher soil water content. About 63% of May precipitation fell three days before and two days after planting. These results support those of Groya and Sheaffer (1981) who found that moisture level did not affect no-till alfalfa establishment and yield in a poorly suppressed grass sod, either due to low levels of light or by less water uptake by alfalfa seedlings with smaller root systems. This shading effect could have been very high especially in NT0 and affected alfalfa establishment, even though the sward was completely controlled after two to three weeks. Results from both 2004 and 2005 trials indicate that one-pass herbicide application and planting will likely be ineffective for establishing alfalfa into a high stand of established perennial cool season sod and conventional post-emergence weed control in western Montana.

Insect damage was similar between NT4 and NT2 in the 2004 experiment. However, NT0 could have been affected by insects more than other treatments, reflected in the low plant population. No signs of aboveground dead plants were observed. In Kalispell, MT spraying four weeks prior to planting alfalfa allowed sufficient time for grass desiccation, allowing sunlight to penetrate to the soil surface, drying out the furrows thereby providing a less favorable environment for slug (*Agriolimax reticulatum* Muller) (Welty et al., 1981). It appears that the insecticide control after emergence was effective and no apparent detrimental effect on yield was observed in the establishment year. The use of insecticide at planting during the 2005 experiment prevented seedling damage in all treatments, however, plant population was still very low in no-till treatments. Other factors like poor drill performance in heavy sod, shading and allelopathic effects could have been more crucial in the establishment process, especially in NT0 in both years.

Planting into a conventionally-prepared seedbed resulted in similar plant populations to NT4 in 2004 and superior stands in 2005 experiment. Soil water content in the 2004 experiment was similar between CONV and NT4, but in the 2005 experiment was lower in CONV than in NT4. Plant population in CONV was 22% higher in the 2004 experiment than CONV in the 2005 experiment, however this difference was higher between the no-till treatments. The CONV seedbed in 2004 experiment was dryer and probably warmer than the no-till treatments. Moist soils warm more slowly than dry soils (Campbell and Norman, 1998). An important difference between the CONV plots from both years was that in the 2005 experiment tilling occurred in

August 2004 and April 2005 whereas in the 2004 experiment only in May 2004. Tilling in the fall could create a better seedbed condition with less weeds at establishment and may enhanced soil water evaporation early than tilling in the spring close to planting, however seedbed condition and moisture appear to be confounded.

The residue layer in the no-till treatments in the 2004 experiment may reduce wind speed at ground level (Campbell and Norman, 1998), reducing evaporation from the soil (Sturgul et al., 1990). Therefore, tilling in the fall reduced soil moisture in the spring and improved seedbed conditions and establishment in CONV with respect to NT4 in the 2005 experiment. In addition, tillage mixes the soil, increase temperature and enhance toxin degradation,reducing allelopathic effect (Toai and Linscott, 1979). The poor performance of the no-till treatments in 2005 experiment could be associated with the residues on the soil surface that result in higher soil moisture and lower spring soil temperature (Crosson, 1981). Therefore the moisture retaining characteristics of no-till is an advantage on droughty soils, but is a disadvantage on poorly drained soils. The site of our experiment is considered a sub-irrigated area, therefore, no-till may be less suitable than other site preparation techniques involving tillage when spring is wet and cold.

Alfalfa yield in the 2004 experiment was highest in NT4, followed by NT2 and NT0. However, weed biomass was similar among no-till treatments. CONV had lower alfalfa yield but equal plant population compared to NT4. The reason for this response was that weed recruitment in CONV not controlled by imazethapyr, was higher than all the other treatments, representing 26% of total biomass yield, while NT4 represented only 13% in the establishment year. Tilling immediately prior to planting did not well control dandelion growth and appeared to enhance weed encroachment with minimal soil disturbance. Therefore, the use of glyphosate four weeks before planting appears feasible for weed control instead of tilling prior to planting. Excess soil water content and low temperatures can affect establishment more dramatically in no-till than a fall conventionally-prepared seedbed.

Alfalfa yield in the post-establishment year was similar between CONV, NT4 and NT2 although the proportion of weeds increased compared to the establishment year, and represented 38, 27 and 49% of total biomass yield in CONV, NT4 and NT2, respectively. Typically, NT2 had less alfalfa yield and equal weed biomass compared to NT4 in the establishment year, but weed biomass was higher in the post-establishment year. Low plant population at establishment increased possibilities for weed encroachment in the post-establishment year. NT0 had very low and weedy yields both in the establishment year and in the post-establishment year.

Weed control after emergence was a key factor in both planting systems, because both tilling and conventional herbicide (imazethapyr) did not well control dandelion which was recruited after planting. These results confirm that conventional tillage planting methods need crop rotations at least one or two years with cereals to improve weed control and maintain forage availability. This management is currently recommended either by using winter or spring cereal forages (D. Cash, personal communication, 2005).

No-till weed management could be improved greatly by using glyphosate on RRA after emergence and throughout the growth cycle. After emergence, weed control with imazethapyr was ineffective for dandelions. However, postemergence weed control with glyphosate in general increased alfalfa yield and reduced broadleaf weeds, although grasses weeds (mostly meadow foxtail and smooth bromegrass) remained similar in the establishment year and the post-establishment years. In the 2004 experiment, herbicides were applied when alfalfa development reached the recommended stage (two to three trifoliate crop growth stage) for imazethapyr. An early application of glyphosate in RRA would probably have improved weed control when weeds are still small and alfalfa was actively growing, but probably an additional application would be necessary. Wilson (2004) reported that two post-emergent applications of glyphosate on RRA when the crop was in the unifoliate leaf stage and then 3 weeks later yielded more alfalfa and less weeds in the establishment year than conventional herbicides applied when alfalfa was in the four trifoliate stage. Selection for resistance or potential shift in species composition towards species that are more difficult to control with glyphosate can occur when timing is not adequate (Fitzpatrick et al., 2004). These results confirm that timing is crucial for weed control, and application of glyphosate when weeds are small would be more beneficial. In addition, visual injury was observed in the conventional post-emergent weed control but when glyphosate was used, phytotoxicity was not observed. These results agree with those of Wilson (2004).

In relation to cultivars, RRA had at least 50% higher plant population than Shaw in both years. However, alfalfa yields were similar during the establishment year but RRA yielded 60% more than Shaw in the post-establishment year. The seeding rate (PLS ha^{-1}) of RRA was only 11% higher than Shaw in 2004, but rates were equal in 2005. The drill was carefully calibrated to deliver equivalent PLS seeding rates in both years. These differences in performance may indicate better establishment vigor in RRA than Shaw. In NT2, the difference in plant population between cultivars was considerable (although PM x CV interaction was N.S.; P=0.056) and the yield of Shaw in the first harvest was very low compared to RRA, but the difference was not evident in the second harvest and not significant in the total alfalfa yield. This may be related to decaying thatch containing glyphosate or toxins released from dead sod may have affected establishment of Shaw more severely. This effect was not significant in NT0 where other factors such as shading or lack of moisture had a stronger influence on establishment and yield. Neumeister (1994) found this problem in Oregon when 2800 kg ha^{-1} of thatch remained on the surface and may have absorbed glyphosate and killed germinating seedlings of perennial ryegrass as they emerged.

Autotoxicity was not evident in either growing season in the 2004 experiment. New seedlings grew well under old alfalfa crowns (field observations), especially in NT4.

Autotoxicity from old alfalfa plants (Miller, 1996) or allelopathic effect from cool-season grasses (Chung and Miller, 1995) has been hypothesized to be an important limitation for sod-seeding alfalfa, but the extent of this effect is not clear (Seguin et al., 2002). It is not possible to elucidate the effect of autotoxicity or allelopathy in the 2004 experiment, and it may have been present in all treatments but less likely in NT4. Tilling in CONV was done two weeks before planting (although sod was pulled out three weeks before planting) as recommended (Tesar, 1993), but spraying-planting interval for NT2 and NT0 were less than the three (Tesar, 1993) or four recommended weeks (Welty et al., 1981). Nevertheless, in the 2005 experiment the difference in plant population between CONV and no-till treatments was greater than that in the 2004 experiment. This effect could be due to enhanced microbial degradation of toxins following tillage. In no-till systems, allelopathic compounds degrade slowly (Roth et al., 2000).

In general, irrigation increased alfalfa yield in a quadratic fashion in the establishment year and linearly in the post-establishment year in the 2004 experiment. The quadratic response for NT4 during the establishment year suggests a negative response to the excessive irrigation at WL5, an effect that was not observed in other planting methods. The linear response in CONV could be related to the high water use by weeds or in NT2 due to the lower plant population and less cover that may enhance water evaporation and efficient water use. Soil surface covered with dead vegetation (No-till in this case) reduces surface water evaporation respect to bare soil (CONV in this case) (Allen et al., 1998).

Irrigation response in the second harvest was in general lower than in the first harvest, despite drier weather conditions. Non-irrigated treatments had high yields, especially in NT4, which could indicate the develop of a deeper root system during first harvest or an increase in the water table. Juster et al. (2002) found that water deficiency during alfalfa establishment in early summer in France reduced root growth and nitrogen reserve accumulation in the fall resulting in fewer crown buds and slower rate of growth during the subsequent spring.

In this experiment, lack of moisture was not the most important reason for failure in establishment in NT2 and NT0; other factors like sod competition for light, allelopathy or even excess of soil water and low temperatures at planting were likely more important. In NT4, where establishment was better, yield response to irrigation was the highest. The effect of irrigation in the post-establishment year was low and linear. Roots may have been deep enough to obtain ground water at this site.

No-till alfalfa into decadent weedy alfalfa stands did not increase total biomass yield during the establishment year. However, alfalfa yield was much greater in the first harvest of the post-establishment year.

The control treatment (CU) representing the actual production of the unmanaged pasture had the highest yield in 2004 since it was harvested three times, one more time than our planting treatments. Weed component was highest in CU (52%) compared to NT4 (13%) and CONV (26%). The difference was greater in the post-establishment year with 74, 27 and 38% of weeds in CU, NT4 and NT2, respectively. This effect may indicate a better forage quality harvested by reseeding, although dandelion, which was the most important weed, has high forage quality compared to grasses (Marten et al., 1987).

Conclusions

The most successful no-till treatment (NT4: spraying glyphosate four weeks before planting) yielded 45% more alfalfa and 23% more total biomass yield than the conventional planting system (CONV) during the establishment year. However, differences were non significant in the post-establishment year. NT4 was the more successful no-till treatment in a warmer and dryer spring, but not in a colder and wetter spring. NT4 provided high forage yield compared to other no-till treatments and CONV, but dandelion encroachment was high especially in the post-establishment year. Performing one-pass selective herbicide application and planting (NT0) will not likely be possible because of excessive competition from resident vegetation regardless of moisture level. Controlling weeds after emergence in a RRA planting with glyphosate looks promising for broadleaf weed control compared to conventional herbicides, although tolerance of some established perennial grasses to glyphosate was observed. RRA had better establishment vigor and equal yield in the establishment year and 60% more yield in the post-establishment year than Shaw, the conventional alfalfa entry. Irrigation increased alfalfa yield in all planting methods, and it appears that irrigation was especially important in NT4 compared to the other treatments. These results indicate that sward productivity may be increased by a no-till alfalfa system that should provide many of the establishment year benefits (less erosion, less time consuming and costs) with better response to irrigation. Irrigation increased yield and may be considered especially in a dry year, if water is available. Additional evaluations and studies to determine long-term response and persistence in no-till planting systems in western Montana are needed. Uncontrolled weeds after emergence reduces yield and potentially quality of forages. Better methods of weed control after emergence are needed, either by the use of glyphosate with RRA or fall sod control to improve weed management by respraying early in the spring three to four weeks prior to planting.

Implications

The no-till technique appears to be a suitable alternative to tilling for alfalfa growers in western Montana to renovate thin alfalfa stands, although further evaluations are needed to measure plant population and production after the establishment year. Delaying four weeks between spraying and planting plus irrigation during the establishment year appears appropriate under local conditions to harvest a high yield during the establishment year. Post-emergent weed control will be necessary for better establishment, yield, and forage quality. Glyphosate-tolerant alfalfas using only glyphosate for weed control appears to be well suited for this purpose. The no-till planting technique could help prevent erosion, as well as conserve moisture, reduce water runoff and save time and labor compared to using plowing, summer fallowing and reseeding. A major cost would be the investment in a good no-till drill. However, the benefit of this technology include planting in rocky soils, less time and fuel consuming, faster turn around (vs. crop rotation), and lower establishment costs than preparing a conventional seedbed.

EXPERIMENT 2: CONVENTIONAL VS. NO-TILL ADAPTED GRASSES AND LEGUMES

Material and Methods

Study Site

The experiment was performed adjacent to Experiment 1.

Experiment Design

Experiment 2 was seeded in two planting seasons (PS), the early summer (ES, 23 June 2004) and the late summer (LS, 28 Aug. 2004). Both planting season trials were established independently as a randomized complete block design with a split-plot arrangement of treatments. Main plots (3 by 18 m) consisted of two planting methods, a conventional seedbed (CONV) and no-till (NT). Subplots consisted of six perennial grasses and five perennial legumes (SP) seeded in 3 x 1.6 m plots.

Sod Control

Roundup UltraMax™ (glyphosate, 4.7 kg a.i. ha^{-1} in 190 L ha^{-1} of water) and ammonium sulphate (1.8 kg ha^{-1}) were sprayed for sod control in ES and LS. In ES, a tractor sprayer was used in CONV whole plots (15 April 2004) and a backpack sprayer for NT whole plots (19 May 2004). On 6 May 2004, the CONV whole plots were rototilled (8 passes). In LS, the entire experimental was sprayed with glyphosate on 1 Aug. 2004 and CONV whole plots were tilled with a cultivator (20 cm deep) and then rototilled (6 passes) from 17 Aug. to 24 Aug. 2004.

Crop Management

Furadan (carbofuran), was sprayed at 0.36 L a.i. ha^{-1} in ES on 3 June 2004 to control insects on existing alfalfa plants that could damage seedlings. LS plots were not sprayed with insecticide. Planting was accomplished with the Truax™ drill described in Experiment 1. Planting was done after packing the conventional plots and mowing the NT plots with a flail mower. Species seeded and seeding rates are given in Table 13. No fertilizers were applied at planting.

For broadleaf and grass weed control in ES, legume subplots (excluding cicer milkvetch) were treated 43 DAP with Pursuit™ (imazethapyr) at 0.106 L a.i. ha^{-1} and 51 DAP with Poast plus™ (sethoxydim) at 0.380 L a.i. ha^{-1} with a non-ionic surfactant (0.45 L ha^{-1}) and ammonium sulphate (1.8 L ha^{-1}). Grasses from ES were sprayed with Low Vol 4™ isooctyl [2-ethylhexyl ester of 2,4-D] at 0.175 L a.i. ha^{-1} in 190 L ha^{-1} 38 DAP. LS plots were not sprayed with herbicides because of insufficient growth of legumes in LS.

The ES treatment was irrigated 12 times (total 310 mm) by sprinklers to meet evapotranspiration rates during the establishment period from 1 July 2004 through 8 Sep. 2004. LS was irrigated three times with an application of 50 mm of water between planting and the first week of September 2004.

Measurements

Plants counts were done on 12 July 2004 (18 DAP) and 7 Oct. 2004 (40 DAP) in ES and LS, respectively by counting the plants in two 1-meter segments of row selected randomly within each subplot. Although DAP were different between the planting seasons, the crop growth stages were similar. No measurements were taken in the 0.20-m border of the plots to reduce border effects.

Table 13. Cool-season perennial grasses and legumes description, recommended and actual pure live seeding rates utilized in ES and LS experiments.

				Planting season (PS)			
Species (SP)	Common name	Cultivar	Target[†]	ES	LS	ES	LS
<u>Legumes</u>				------PLS m^{-1} row------		---kg ha^{-1}---	
Medicago sativa L.	Alfalfa	Shaw	46	72	61	12.9	10.9
Medicago sativa L.	Alfalfa	RRA[‡]	46	80	65	13.8	11.2
Astralagus cicer L.	Cicer milkvetch	Lutana	46	25	26	11.3	11.6
Lotus corniculatus L.	Birdsfoot trefoil	Norcen	89	31	37	5.3	6.3
Onobrychis viciifolia Scop.	Sainfoin	Remont	52	41	40	91.4	88.6
<u>Grasses</u>							
Elymus hoffmannii Jensen & Asay[§]	Hybrid wheatgrass	NewHy	39	52	65	12.3	15.4
Agropyron cristatum (L.) Gaertn. × *Agropyron desertorum* Gaertn.	Hybrid crested wheatgrass	Hycrest	39	55	51	11.3	10.5
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey	Intermediate wheatgrass	Oahe	39	45	50	12.9	14.3
Bromus riparius Rehm	Meadow bromegrass	MacBeth	36	57	54	18.6	17.7
Festuca arundinacea Schreb	Tall fescue	HiMag	52	70	63	17.1	15.4
Thinopyrum intermedium (Host) Barkworth & D.R. Dewey subsp. barbulatum (Schur) Barkworth & D.R. Dewey	Pubescent wheatgrass	Luna	39	56	44	24.9	19.7

Planting seasons = ES: early summer (23 June 2004); LS: late summer (28 August 2004).

† Target seeding rates of pure lLive seeds (PLS m^{-1} row) for subirrigated areas. The same recommended seeding rate was used among wheatgrasses. Source: Holzworth and Wiesner (2005).

‡ RRA is a glyphosate-tolerant experimental line termed “Roundup Ready alfalfa”™ provided by Forage Genetics International, Nampa,ID.

§ NewHy: A hybrid of quackgrass (*Elytrigia repens* (L.) Nevski) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh.) A. Love). Source : Asay et al., 1991.

Forage yield was not estimated in 2004 due to limited growth and potential damage from a late fall harvesting. In 2005, yield was estimated in both planting seasons by hand-clipping one quadrat of 0.5 m^2 to a 4-cm height on 8 June 2005. Forage material was weighed in the field and two sub-samples (about 200 g) taken from each subplot. One sample was hand-separated into target species, grasses and broadleaves weeds, and oven dried with the other sample for a week at 42 ^{o}C and reweighed for dry matter determinations.

Statistical Analysis

Data were analyzed combined across both planting seasons and subjected to analysis of variance with the PROC MIXED procedure (SAS Inst., 2002). Planting season, planting method and species were considered fixed effects, and blocks were considered random in the model. Blocks were nested within planting season (ES, LS) and any of the interactions with blocks were considered random. Individual subplots (n=176) were the experimental units. Parameter sets showing excessive deviation from normality or non-homogeneous variance were subjected to transformation after testing the appropriate power transformation (Kuehl, 2000). Non-transformed data are presented in tables and figures. Mean separations were conducted with Fisher's protected least significant difference (LSD) at the 0.05 level of probability. Single degree of freedom contrasts were used to conduct preplanned comparisons between grasses and legumes.

Results and Discussion

Plant Population

Stands of the 11 forages varied significantly due to planting method (PM), species (SP) and the interactions of planting season (PS) x PM, PS x SP and PM x SP (Table 14).

Table 14. *P*-values from F-test from ANOVA for plant population, and yield from two planting seasons, two planting methods and 11 forage species, during 2005 growing season at Bozeman, MT.

Source of variation	df	Plant population	Yield: Target	Yield: Weeds[†]	Yield: Total
		---- *P*-value ----			
Planting season (PS)	1	0.872	<0.001	0.057	0.012
Planting method (PM)	1	<0.001	0.642	0.411	0.132
PSxPM	1	0.006	0.726	0.036	0.017
Species (SP)	10	<0.001	<0.001	<0.001	<0.001
PSxSP	10	0.019	<0.001	<.001	0.001
PMxSP	10	0.009	0.813	0.939	0.903
PS x SP x PM	10	0.463	0.421	0.311	0.684

[†] Total of broadleaf weeds and grasses.

Plant populations were significantly higher for CONV compared to NT, but did not vary between ES and LS (Table 15). CONV had higher plant population than NT in both planting seasons, but planting season did not affect plant population in CONV. However, in LS plant population was greater in NT than in CONV. This response could be related to better sod conditions for germination in LS, with some of the resident sod grasses in dormancy, thus affecting competition at establishment that favored the no-till treatment with respect to ES.

Table 15. Effect of planting method and planting season on plant population.

	Planting Method (PM)	
Planting season (PS)	Conventional (CONV)	No-Till (NT)
	------------------------------- plants m^{-1} of row -------------------------------	
Early summer (ES)	37 a[†]X[†]	16 bY
Late summer (LS)	32 a X	22 aY

[†] Means sharing a different lowercase letter vertically (a,b) or a different uppercase letter horizontally (X,Y) are different at the 5% level of significance based on Fisher's protected LSD test.

The PS x SP interaction was significant for plant population (Table 14). In this case, no differences between ES and LS were observed but rankings among species were different within planting season (Table 16). Differences in plant population among species were expected, because target recommendations of planting rates and actual seeding rates varied.

Table 16. Effect of planting method, planting season, and species on plant population in 2004.

	Planting season (PS)		Planting method (PM)	
Species (SP)	Early summer (ES)	Late summer (LS)	Conventional (CONV)	No-Till (NT)
	------------------------- plants m^{-1} of row -------------------------			
<u>Legumes</u>				
Sainfoin	30	29	39 X[†]	20 Y
RRA alfalfa	25	23	33 X	16 Y
Shaw alfalfa	21	26	29 X	17 Y
Birdsfoot trefoil	17	15	20 X	12 Y
Cicer milkvetch	12	4	10	7
Avg. legumes	*21*	*19*	*26*	*14*
<u>Grasses</u>				
Pubescent wheatgrass	46	36	50 X	32 Y
Hybrid crested wheatgrass	30	28	39 X	19 Y
Tall fescue	31	39	45 X	25 Y
Intermediate wheatgrass	28	34	38 X	23 Y
'NewHy' hybrid wheatgrass	25	29	36 X	19 Y
Meadow bromegrass	25	34	41 X	18 Y
Avg. grasses	*31*	*33*	*42*	*23*
$LSD_{0.05}$ by column[‡]	7.6		8.2	

[†] Means sharing a different letter uppercase horizontally (X,Y) between planting method are different at the 5% level of significance based on Fisher's protected LSD test.
[‡] $LSD_{0.05}$ for comparing means within a column.

Although differences in plant population between ES and LS were not significant, the actual seeding rates between planting seasons in some species were different, even though the same drill settings were used, and all seeding rates were calibrated in the field and adjusted to PLS. Another approach to compare species is through the establishment rate (Fig. 11).

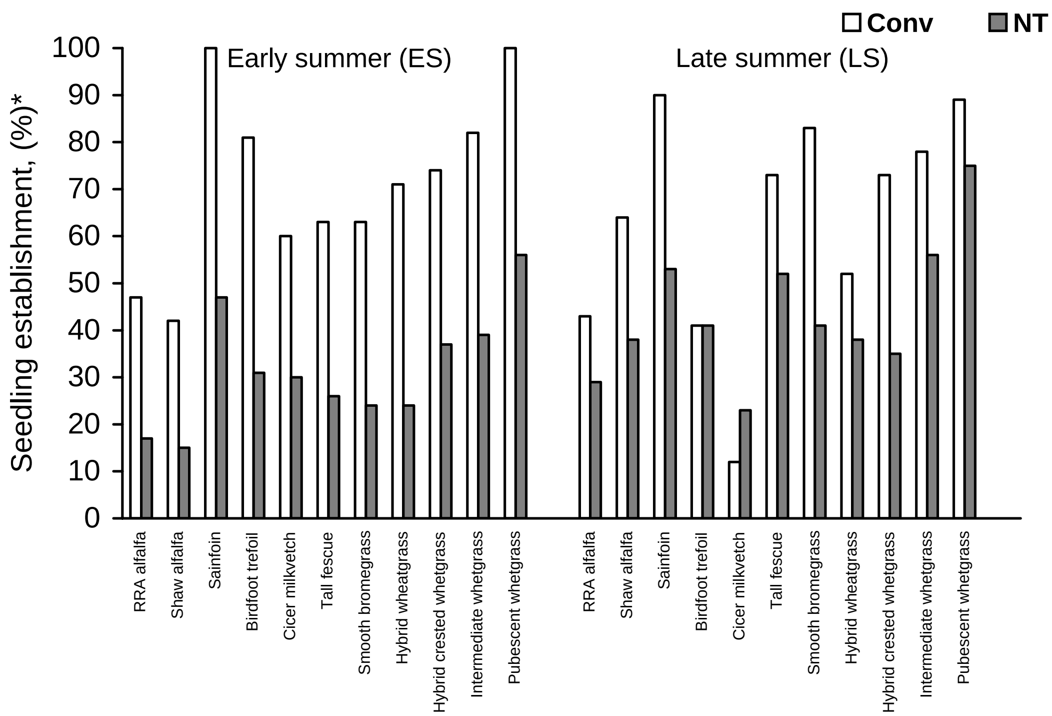


Fig 11. Effect of planting method and species on plant establishment in two planting seasons. *Seedling establishment = (actual plant population /actual PLS seeding rate) x 100. Prior to planting, all species were tested for 30-day emergence under ideal greenhouse conditions to determine PLS seeding rates.

Pubescent wheatgrass and sainfoin had the highest establishment rate in both planting seasons in both planting methods, and appear to be very promising forages for no-till planting. 'Luna' Pubescent wheatgrass has been characterized as having excellent seedling vigor and establishment (Holzworth et al., 2003). Luna and Hycrest competed well with downy brome (*Bromus tectorum* L.)-musk thistle (*Carduus nutans* L.) infested areas in WY after spraying and rototilling reducing weed yield (Rose et al., 2001). Sainfoin had high establishment in both planting seasons, likely because of its large seed size and strong seedling vigor (Ditterline and Cooper, 1975). Alfalfa in ES and cicer milkvetch in LS had the lowest establishment. Cicer milkvetch typically has slow emergence, poor vigor and more than two seasons are frequently required for this legume to become established (Alberta Agriculture Food and Rural Development, 1981) and it is less competitive with weeds and yields than alfalfa (Cash, 2005b). The interaction of PM x SP was significant and CONV had more plant population than NT in all species. Cicer milkvetch had very low plant populations in both planting methods (Table 16). Cicer milkvetch was the only species in ES where postemergence weed control was not performed due to delayed seedling development, and this factor could severely influence establishment. Therefore poor vigor is not a good trait for conventional tillage and no-till. However, cicer milkvetch has been sod seeded successfully in autumn or spring following glyphosate suppression of the existing sward in northeastern Saskatchewan (Malik and Waddington, 1990). Establishment was poor but plant percent cover increased over time in spite of the grazing pressure. Therefore an increase in cover in cicer milkvetch is expected in further seasons.

<u>Forage Yield</u>

Target yield (yield from each seeded forage crop species) was higher in ES than LS but equivalent between NT and CONV without significant PS x PM interaction effect (Table 17). Although plant populations were similar between ES and LS, early summer planting in 2004 favored a higher yield in the first harvest of 2005. Target yield was different among species with a significant PS x SP interaction, where in general ES outyielded LS.

Birdsfoot trefoil and cicer milkvetch had very low target yields, less than 705 kg ha^{-1} (Table 18). These species also had low plant populations for both planting methods and planting seasons likely due to lower seeding rates than recommended (Table 13) and the typical slow establishment of this species (Alberta Agriculture Food and Rural Development, 1981). Birdsfoot trefoil seeds are small and the Truax™ drill was not able to properly meter the seed.

Table 17. Effect of planting method and planting season on first-cut forage in 2005.

	Planting method (PM)	
Planting season (PS)	Conventional (CONV)	No-Till (NT)
	---------- kg DM ha^{-1} ----------	
	Target	
Early summer (ES)	4292 a†X†	4574 aX
Late summer (LS)	998 bX	1038 bX
	Weeds	
Early summer (ES)	2124 aX	1372 bX
Late summer (LS)	2141 aY	3629 aX
	Total	
Early summer (ES)	6416 aX	5945 aX
Late summer (LS)	3139 bY	4667 aX

† Means sharing a different lowercase letter vertically (a,b) by yield component or a different uppercase letter horizontally (X,Y) within a row are different at the 5% level of significance based on Fisher's protected LSD test.

Grasses had at least three times higher yield than legumes for both planting seasons and therefore appear more reliable species than legumes in both planting systems. In general, better establishment and better weed control resulted in superior performance in grasses compared to legumes (Table 18).

Excellent stands and high yields obtained in grasses make no-till a promising tool to improve pastures according to local conditions and forage requirements. Meadow bromegrass outyielded all the species in ES, but it was similar to pubescent wheatgrass, hybrid crested wheatgrass and intermediate wheatgrass as the best entry in LS. Sainfoin had the highest yield among legumes, but it was only equal to the lowest grass yield. Under irrigated conditions in Bozeman, meadow bromegrass has been one of the most productive grass species during the year after planting (10,300 kg DM ha^{-1}) and also during three years after planting (Cash, 2005a). This experimental site corresponds to a subirrigated condition and higher rainfall, therefore it might be a suitable area for meadow bromegrass.

The PS x PM interaction was significant for weed biomass. In ES, CONV and NT had similar weed biomass, but in LS, weed encroachment was higher in NT than CONV (Table 17). Weed biomass was similar between planting seasons in CONV, but in NT it was greater in LS than ES. Proportion of weeds from the total biomass yield was higher in LS, and the treatment that resulted in the highest weed biomass was NT in LS. In LS, effective sod control may be limited when some grasses (mostly smooth bromegrass, meadow foxtail, Kentucky bluegrass) are dormant due to photoperiod. On the other hand, a larger seedbank of weeds could be expected, due to high infestation of dandelions (see table 2), which could be a limitation in late season planting, especially when no postemergence or early spring weed control is performed.

The PS x SP interaction was significant for weed biomass. Legumes had similar weed biomass between planting seasons, higher than for grasses in both planting seasons. However grasses had more weed biomass in LS than ES (Table 18). Weed biomass was similar among grasses in ES, but legumes differed for weed biomass, with the highest in cicer milkvetch plots. However in ES grasses, weeds were controlled with postemergence herbicide, but grass plots were not treated with herbicide in LS. Therefore, the reason for high weed encroachment in ES is that in spite of the apparent satisfactory sod control by glyphosate, the recruitment of dandelions was high and post emergence weed control with imazethapyr in legumes was unsatisfactory. Imazethapyr did not control dandelions well compared to isooctyl that was used in grasses. Weeds averaged 67 and 4% of total biomass yield in legumes and grasses, respectively in ES while in LS it represented 89 and 61%. Weeds not controlled by glyphosate may increase after herbicide treatment due to reduction of competition and perennial weeds that grow in patches may increase.

Table 18. Effects of planting season and species on first-cut forage in 2005.

	Yield					
	Target		Weed		Total	
Species (SP)	Early summer (ES)	Late summer (LS)	Early summer (ES)	Late summer (LS)	Early summer (ES)	Late summer (LS)
	---------- kg DM ha^{-1} ----------					
Legumes						
Sainfoin	2224 d[†] X[†]	1063 aY	2795 bc	2832 bc	5019 fg	3895 ab
RRA alfalfa	2868 dX	458 bY	2755 c	4053 a	5622 def	4511 ab
Shaw alfalfa	2045 dX	470 bY	2999 bc	3199 ab	5043 efg	3669 ab
Birdsfoot trefoil	705 e	51 b	3744 b	3273 ab	4450 g	3324 ab
Cicer milkvetch	583 e	0 b	5159 a	3925 a	5742 cdeX	3925 abY
Mean legumes	*1685*	*408*	*3490*	*3456*	*5175*	*3865*
Grasses						
Pubescent wheatgrass	6799 bX	2092 aY	0 dX	1649 dY	6799 bcX	3741 abY
Hybrid crested wheatgrass	6773 bX	1986 aY	185 dX	2422 bcdY	6958 bX	4408 aY
Tall fescue	5752 cX	881 bY	812 dX	2817 bcY	6564 bcdX	3698 abY
Intermediate wheatgrass	6751 bX	1743 aY	157 dX	1995 cdY	6908 bX	3737 abY
NewHy hybrid wheatgrass	6132 bcX	815 bY	233 dX	2751 bcY	6365 bcdX	3566 abY
Meadow bromegrass	8127 aX	1640 aY	385 dX	2818 bcY	8512 aX	4458 aY
Mean grasses	*6722*	*1526*	*295*	*2409*	*7018*	*3935*

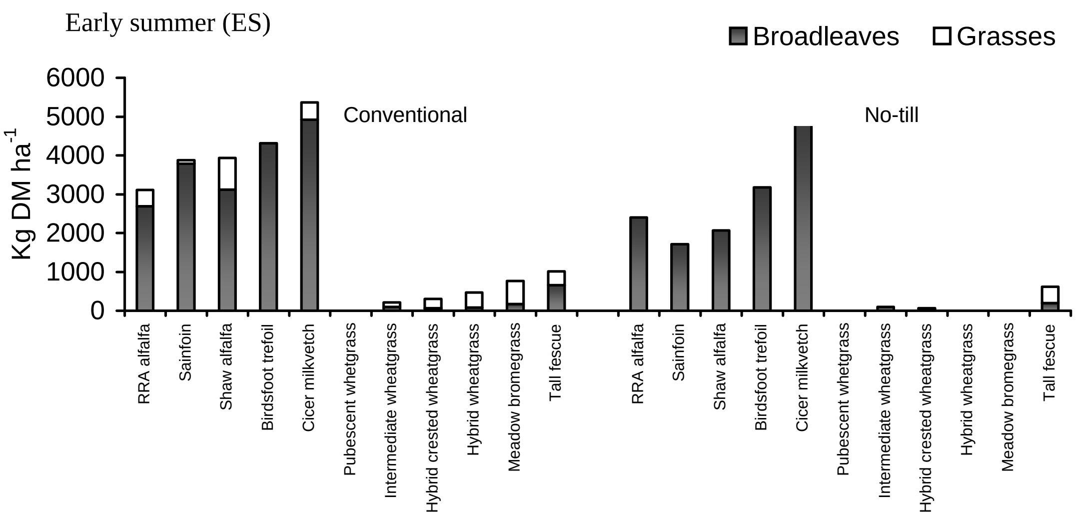
[†] Means sharing a different lowercase letter vertically (a,b,c,d,e,f,g) within a column or a different uppercase letter horizontally (X,Y) between planting seasons within each yield component are different at the 5% level of significance based on Fisher's protected LSD test.

Therefore, the effectiveness of glyphosate for weed control, however, will be influenced by the timing of glyphosate application relative to weed seedling emergence and growth stage of the sod species and forage species.

Weed species were different among treatments. In ES dandelion predominated in CONV and in NT, but in LS, dandelion, field pennycress (*Thlapsi arvense* L.), shepherdspurse (*Capsella burs-pastoris* L. Medic.), and flixweed (*Descurainia Sophia* L. Webb. Ex Prantl) were most prevalent in CONV. Grassy weeds (Kentucky bluegrass, meadow foxtail) were the most important components in NT in LS (Fig. 11).

Total biomass yield in ES was similar between NT and CONV, but in LS, NT had more total biomass yield than CONV. However, CONV in ES had more yield than LS, without differences in NT (Table 17). Total biomass yield had significant differences among species without a significant PM x SP interaction effect, but the interaction PS x SP was significant. Combined over planting method, total forage production was in general equal between PS in legumes (but cicer milkvetch had more yield in ES) but higher in ES in grasses. Among grasses the yields were similar, but higher than legumes with the highest yield in meadow bromegrass and the lowest in birdsfoot trefoil (Table 18).

Under these conditions a no-till planting system in ES appears more suitable than LS and for grasses more than legumes. Broadleaf weeds in legumes could be difficult to control if dandelion plants regrowth or emerge after spraying or tilling. Rioux (1994) reported substantial dandelion infestation of a smooth bromegrass sward renovated with alfalfa. Both alfalfa cultivars did not compete well with weeds, however plant populations were higher in ES. For ES there is the opportunity to use RRA in no-till in areas were weeds are abundant or difficult to kill. Glyphosate could be applied throughout the establishment season to suppress resident vegetation and emerging weeds (Wilson, 2004) similar to the results presented in the Experiment 1 for no-till RRA where spraying and planting was done in the same pass. However, more research is needed to evaluate shift of weed species and resistance to glyphosate due to timing of application, avoidance mechanisms and dormancy.



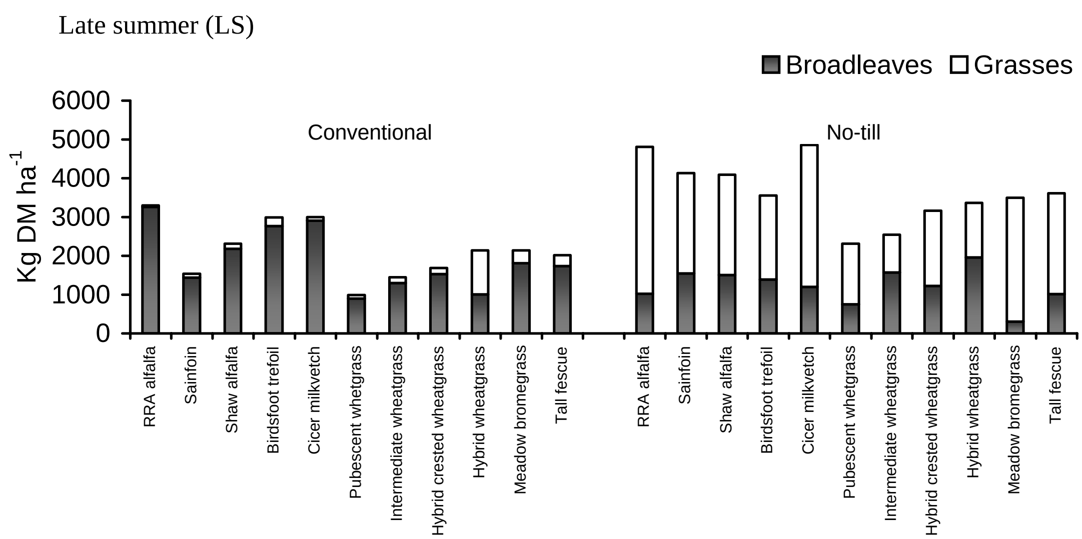


Fig. 12. Effect of planting method and species on weed biomass in post establishment year in early summer and late summer, year 2005.

LS planting was not effective for legumes. Sainfoin had some potential in LS, but weed control in late fall or early spring could benefit legume performance. Grassy (smooth bromegrass, meadow foxtail, Kentucky bluegrass) weed regrowth was also a problem, especially in no-till grasses, because of lack of selective herbicides.

An important aspect to consider related to establishment and yield evaluation of grasses is that the performance of forages species the first year does not always represent their performance the second and subsequent years. The no-till grasses in ES increased forage yield of the site by 81%, reducing considerably yield contribution of weeds during the first cut after the establishment year (the control treatment in rainfed [CU in WL1] of Experiment 1, yielded 3752 kg DM ha^{-1} with 70% weeds). Therefore the no-till grass pasture renovation technique increased yield significantly and may increase hay quality (because of less weeds) although under grazing conditions the quality may be similar. Long-term studies are necessary in no-till forages to evaluate weed encroachment and stand decline, because improper grazing or harvest management can decrease stands and increase weed pressure. In alfalfa Cash et al., (2005b) reported that improper late summer harvest decreased yield and increased weeds in Bozeman, MT.

Forage Quality

Although forage quality was not measured in this research, it is pertinent to relate forage yield and quality because both factors are of interest for livestock production. Dandelion, which was the dominant weed species present, has a relatively high quality compared to grasses (Marten et al., 1987), but yields less than grasses. Blunt in (2001), reported similar yields among hybrid crested wheatgrass, pubescent wheatgrass and intermediate wheatgrass (2000 kg ha^{-1}) harvested during three year in the second week of June in Bozeman, MT, but the forage quality varied among entries. Means for crude protein 16.1, 18.3, 17.1 and digestibility 47.5, 51.0, and 52.4. White and Wight (1984) reported less *in vivo* dry matter digestibility in pubescent wheatgrass than meadow bromegrass in the summer during the year after planting, but similar regrowth yield and quality in the fall compared to crested wheatgrass. Therefore grass no-till renovation technique would increase yield and decrease weed content of the pasture significantly, but increases in forage quality may not occur.

Conclusions

No-till planting forage with legumes and grasses in the summer resulted in yields similar to those following conventional seedbed preparation. However, target yields where higher following planting in early summer (23 June) than late summer (28 Aug.), confirming that planting in early summer is more successful. Grasses had three times higher target yields than legumes when no-till planted into an old alfalfa/bromegrass stand. Meadow bromegrass appears to be a highly dapted species for no-till. Broadleaf weed invasion was greater in the early summer planting season legumes because imazethapyr did not control old dandelion regrowth. In contrast, isooctyl controlled dandelions and other broadleaf weeds in grasses and they competed better with weeds. The use of chemical sod suppression in early summer to plant grasses in no till appears to have potential to enhance forage production of old alfalfa fields. The strategy of late summer planting was less successful due to poor sod control, resulting in high weed encroachment and low target forage yields the year after planting. To enhance productivity of old alfalfa fields, more research is required in sod and post planting weed control, especially for legumes establishment.

Implications

No-till planting appears to be a suitable and fast alternative to increase dry matter productivity and forage quality in depleted pastures or hayfields. This method would be a feasible alternative in stands where it is not economical or sustainable to plow out established stands and re-seed forages. High populations of resident weeds in the seed bank and weed recruitment is a major limitation for no-till forages and post-emergent weed control strategies will need to be developed. Late summer no-till planting appears to be highly dependent on sod control, and increased weed encroachment is expected the following year. However early control in the following spring may solve this problem. RRA offers a unique opportunity to cope with weed issues in tilled and no-till systems.

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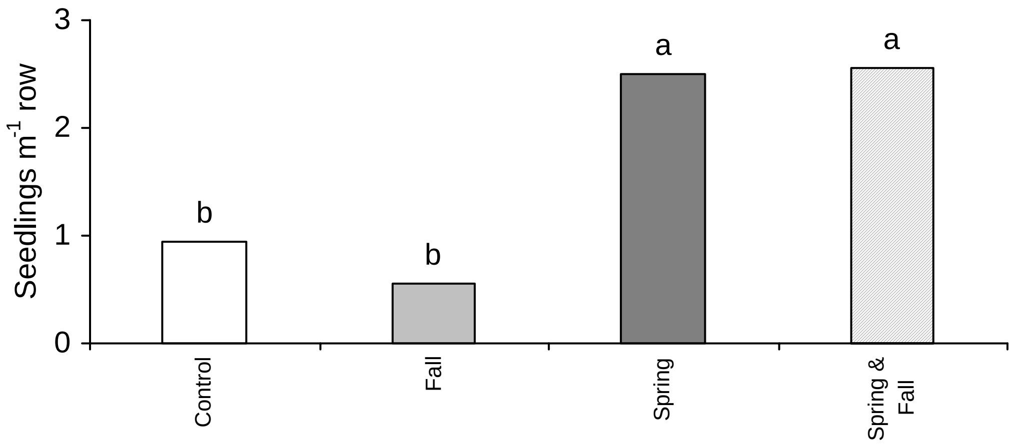
APPENDIX A

EFFECT OF INSECTICIDE APPLICATION ON PLANT POPULATION IN NO-TILL ALFALFA



Appendix A. Effect of insecticide application on plant population in no-till alfalfa. Control: No use of insecticide; Fall: Liquid Furadan (Carbofuran) sprayed in the fall at 0.36 L a.i. ha^{-1}; Spring: Granular Furadan 10G (Carbofuran) applied with the drill at 1.2 kg a.i. ha^{-1}; Spring & Fall: Both treatments Fall and Spring were applied. The treatments were planted (21 May 2005, RRA at 75 PLS m^{-1} row) and sprayed with glyphosate (6.0 kg a.i. ha^{-1}) the same day. Different letters among bars are different at the 5% level of significance based on Fisher's protected LSD test.