Evaluation of Weed Management Practices in White Lupin (*Lupinus albus* L.)

by

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Abstract

Worldwide, 450 lupin species can be found with 4 species currently grown. The cultivated species consist of three old world species white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.) and blue lupin (*L. angustifolius* L.) and the new world species Andean lupin (*L. mutabilis* Sweet). Between 1930 and 1950 lupins were grown on 1 million ha in the Southeastern United States. The US lupin production declined after the 1950s for various reasons including: 1). discontinued government support for green-manure, 2) N-fertilizers became affordable and 3) early freezes during two consecutive years that severely reduced seed stock. White lupin is of major interest in the southeastern USA because winter hardy cultivars are available. White lupin grows best on well drained sandy loams, loamy soils and sands and tolerates a pH range of 5.5 to 6.8. Except for the Black Belt, most soils in Alabama fulfill these requirements. White lupin is a poor weed competitor during its early establishment which makes effective weed control necessary. Therefore, the objectives of this experiment are to investigate various weed management practices and evaluate their effect on weed control and white lupin performance (plant density, crop injury, yield, height and yield components). A two-year experiment was established at the Field Crops Unit as well as the Plant Breeding Unit, E. V. Smith Research and Extension Center of the Alabama Agricultural

Experiment Station near Shorter, AL. Our treatments included ten PRE-applied herbicides, nine POST-applied herbicides well as organic treatments (2 cover crop living mulch, 2 mechanical weed control practices). Response variables measured were weed control, crop injury, plant density, grain yield, seed mass, plant height, number of yield components and seed yield per plant. Over the course of the experiment 14 weed species were encountered. Best control (>80%) of the most troublesome weed species, i.e. henbit (*Lamium amplexicaule* L.), Carolina geranium (*Geranium carolinianum* L.), wild radish (*Raphanus raphanistrum* L.) and corn spurry (*Spergula avensis* L.) was achieved with PRE applied diclosulam, metribuzin, pendimethalin, imazethapyr, *S*-metolachlor, and a mixture of *S*-metolachlor/linuron. Good control (>90%) of annual ryegrass (*Lolium multiflorum* Lam.) and annual bluegrass (*Poa annua* L.) by POST-applied herbicides was achieved by sethoxydim and fluazifop. More than 80% non-selective weed control was achieved by the POST-applied glyphosate. PRE-applied diclosulam and flumioxazin resulted in unacceptable crop injury and subsequent yield loss in both years. POST-applied thifensulfuron and chlorimuron caused complete crop injury (death) of all three cultivars which resulted in crop density reduction and severe yield loss in 2007. Hence these herbicides were excluded in study year 2008. The application of glyphosate lead to inacceptable crop injury and significant yield reduction, but did not significantly reduce crop density. Diclosulam, fomesafen and glyphosate significantly reduced lupin height, number of fruiting branches and seed yield. Summing up, it can be stated that the chemical treatments [*S*-metolachlor/linuron mixture, pendimethalin, imazethapyr (PRE and POST), 2,4-DB, sethoxydim and fluazifop] and all organic treatments offered good

weed control without causing inacceptable crop injury and yield loss. However, our data showed that the lupin cultivars yielded well even without the use of weed control practices.

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I. LITERATURE REVIEW

Botanical Description

Around 450 *Lupinus* species can be found world wide (Dierauer et al., 2004), most of them in North America (Wilbur, 1963). North America, South America and the Mediterranean region are the three primary centers of origin (Wilbur, 1963; Wink et al., 1999, Noffsinger and van Santen, 2005). Based on these centers of origin Lupin species are grouped into old world and new world species. Lupins belong to the botanical family Fabaceae (third largest family), also referred to as Leguminosae (Castner, 2004). The four major species in use today are three old world species; white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.), narrowleaf or blue lupin (*L. angustifolius* L.) and one new world species Andean lupin (*L. mutabilis* Sweet). Other members of the Fabaceae include *Trifolium* L. and *Medicago* L. Lupins are annual, biennial and perennial herbs (Radford et al., 1968), which grow to a height of 80 to 120 cm (Duke, 1981). Their alternating, palmately compound leaves, with 5 to 15 leaflets, can move by pulvini on the base of their petioles and petiolules. These pulvini enable the movement of leaves towards the sun, a mechanism called heliotropism. At night the leaflets will fold down (Castner, 2004). Papilionaceous flowers can be found on the inflorescence, the raceme, which is 5 to 10 cm long (Duke, 1981). The fruit type is referred to as a legume, which can contain between three to six seeds (Duke, 1981).

Soil and Climate Requirements

Duke (1981) stated lupins to be cold tolerant, but that this tolerance is subject to variation within species and cultivars. *L. angustifolius* tolerates frost to -8° C after planting while *L. luteus* and *L. albus* tolerate frost to -4° C after emerging (Gesellschaft zur Förderung der Lupine, 2007). This tolerance led to the good adaptation of white lupin as a winter annual crop in the southern United States. Table 1.01 (2007) by the Society for the Promotion of Lupins (Gesellschaft zur Förderung der Lupine) was translated from German into English and compares the basic soil and climate requirements of each species.

All lupin species are very sensitive to water logged and poorly drained clayey soils (Gesellschaft zur Förderung der Lupine, 2007). Lupins are generally considered to be relatively drought tolerant due to a deep taproot and subsequent efficient water uptake ability. This may be important during droughts common in the Southeast.

Most Alabama soils are suitable for this crop. The Piedmont Plateau has red clayey subsoils with sandy loam or clay loam on the upper surface. The Coastal Plains have characteristic loamy subsoils, but the surface is loamy sand or sandy loam. The Black Belt which is the area of central and western Alabama is named for its black surface in which alkaline and acetic soils are mixed. Some of these blackland prairie soils i.e. the clayey Vaiden and Wilcox are acid (Alabama Cooperative Extension System, 2008). However soils in the black belt are poorly drained and not suitable for lupin.

Faluyi et al. (2000) found that an early planting date and the choice of cultivar had major influence on the oil and protein concentration in the grain whereas the concentration was not affected by row width. Experiments conducted by Payne et al. (2004) in the Pacific Northwest showed a maximum white lupin yield of 2128 kg ha^{-1}, but yield was not stable. They also found that yield could be maximized with earlier planting dates. It was found that the optimal planting date for white lupin in mid-Atlantic region is early October with an optimum row spacing of 0.3 m. Oil content of *L. albus* was affected positively by planting date and row spacing (Bhardwaj et al., 2004).

Economic Importance

Utilization of *Lupinus albus* L. during the past 3000 years included its use as a cover crop, livestock and food crop (Noffsinger and van Santen, 2005). 2000 years ago Roman philosopher Virgil noticed its positive effects in a lupin-wheat rotation (Payne et al., 2004). Domestication of white lupin began in Germany during World War I due to the need for a high-protein legume adapted to temperate environments (Payne et al., 2004). Reinold von Sengbusch was a major contributor to the breeding of lupin cultivars with low alkaloid content. Von Sengbusch was successful in breeding these cultivars between 1927 and 1931 (Gesellschaft zur Förderung der Lupine, 2007). A lupin that contains less than 0.05% alkaloids per grain is called “Sweet Lupin” (Dierauer et al., 2004; Gesellschaft zur Förderung der Lupine, 2007).

Australia is the largest lupin producing and exporting country in the world, accounting for 85% of the world wide lupin production in the last 10 years, averaging 1.2 million tons a year. Approximately, 430,000 tons yearly (value ~ $100 million per year) were exported and about 90% had their final destination in the European Union, Japan and the Republic of Korea (Lawrance, 2007). Germany is the major lupin producing country within the European Union, growing lupin on 33,100 ha annually (Gesellschaft zur Förderung der Lupine, 2007). The interest in lupin in Europe has been increasing within the last few years. Some reasons for this development are the EU-wide ban on the feeding of animal protein and fish meal and the concerns over genetically modified imported protein sources such as soybean, especially in organic production (George, 2005).

In the 1930's white lupin was first introduced into the southeastern United States. Between the 1930 and 1950 lupins were grown on 1 million ha in the Southeastern US (van Santen and Reeves, 2003). Until the 1950's the production grew continuously, then declined for various reasons including:

- Government support for green manuring was discontinued
- N-fertilizers became affordable when the economy shifted from war to peacetime
- Early hard freezes during two consecutive years killed all lupins as far south as Valdosta, GA
- Seed stock reductions (Payne, et al., 2004, Noffsinger and van Santen, 2005).

This development also took place in Alabama's "lupin belt". Bitter lupins were grown exclusively in this belt as a cover crop and for the fixation of nitrogen (Roberson, 1991). Recently, there is renewed interest in this crop in the United States and Canada as an alternative legume crop and for its yield potential. Recent research has been conducted to improve seed quality, genetic improvement for cold, disease and pest tolerance, and determine best management cultural practices (Faluyi, et al., 2000; Payne et al., 2004; Noffsinger and van Santen, 2005).

Lupinus spp. have a diverse spectrum of use. Literature varies in giving the protein content of sweet white lupin. Putnem et al. (1989) reported a protein content of 32-38% whereas Poetsch (2006) gives a content of 35-40%, 9 to 10% oil and no trypsin inhibitors (Putnam et al., 1989, Poetsch, 2006). The amino acid ratio suggests that lupins contain the most "ideal protein" in comparison to other legumes such as beans and peas (Gesellschaft zur Förderung der Lupine, 2007). See table 1.02 for comparison of lupin protein, oil, and energy with other legumes.

For more than 2000 years lupin has been known as a human food source in the Mediterranean regions and Andean regions in South America. Hill (2005) mentioned that the protein availability in soybean and lupin is very high and similar to each other. Lupin can be added to various human foods such as bread, pasta, soups and yogurt-like products without changing their flavor (Hill, 2005). Some health advantages of lupin in human foods are, among others the lack of gluten, which is especially important for people with gluten-intolerance, and the slow availability of carbohydrates which reduces the blood insulin level. But some disadvantages may be the potential development of allergenicity to lupin proteins (Hill, 2005). The alkaloid level in lupins used as/in human food should not exceed 0.02% (Gesellschaft zur Förderung der Lupine, 2007).

Lupins can also be used in monogastric (pigs, poultry) and ruminant (dairy and beef cattle, sheep, goats) feeding and fish in aquaculture. Hill (1990) mentioned that the feeding of lupin seeds to pigs is still questionable, because methionine availablity is limited. However this amino acid is required in monogastric rations (Putnam et al., 1989). Both Hill (1990) and Putnam et al. (1989) mentioned the sensitivity of pigs to higher alkaloid levels in lupins, which reduces appetite. A level of 0.04% or more in the dry matter will result in this loss of appetite and therefore decrease the weight gain (Putnam et al., 1989). But Hill (1990) also mentioned other results where the soybean meal was replaced by *L. albus* and *Vicia faba* flour (10% each) and piglets with a starting weight of 10 kg gained 19.8 kg during a five week feeding trial. It is recommended, however, that the *L. albus* should not make up more than 10% in the pig ration and the alkaloid level should not exceed 0.02% (Gesellschaft zur Förderung der Lupine, 2007). Supplementation of methionine is necessary (Putnam et al., 1989).

In poultry production lupins can make up to 15-25% of the ration (Putnam et al., 1989; Gesellschaft zur Förderung der Lupine, 2007). Higher levels will have negative influence on the consistence of droppings and therefore influence litter hygiene. With rations up to that level the production is the same as in soybean meal diets, but methionine has to be supplemented (Putnam et al., 1989).

Lupins have great potential in ruminant feeding. Hill (2005) stated that raw or roasted *L. albus* as a supplement to grass silage led to the same growth rate as grass silage with soybean meal as supplement. Beef cattle rations can contain up to 30% of lupin (Gesellschaft zur Förderung der Lupine, 2007). The feeding of lupin to dairy cattle influences the fat content of milk. In rations where lupin replaced soy to 75%, cows produced about one kg d^{-1} of fat compared to cows fed with 100% soy (0.97 kg d^{-1}). The milk yield from cows fed 100% lupins or 100% soya showed no difference (Hill, 2005).

The whole feeding ration of dairy cows can contain up to 20% of lupin (Gesellschaft zur Förderung der Lupine, 2007).

The feeding of lupin containing rations to ewes enhances their ovulation rate. It also led to increased conception as well as lambing. The survival was enhanced due to higher colostrum and milk yield. Another advantage of feeding lupins to sheep is better wool growth and quality (Hill, G. D., 2005). Up to 30% of lupin in a ration can be fed to sheep (Gesellschaft zur Förderung der Lupine, 2007).

There is an increased research interest in feeding lupins in aquaculture. Up to 30% of a ration containing lupin can be fed to trout (Gesellschaft zur Förderung der Lupine, 2007). Hill (2005) mentioned that most research shows high protein and energy digestibility of lupin seeds in trout. He also mentioned positive effects of lupin fed to other fish species as well as mollusks and crustaceans.

Weed Control

Weed control practices can be grouped into five categories (Anderson, 1996):

1 Preventive

2 Cultural

3 Mechanical

4 Biological

5 Chemical.

Lupinus spp. are very poor weed competitors during early establishment, since canopy development is slow, resulting in weed seed germination and yield loss due to competition. The maximum vegetative growth is reached during flowering (Putnam et al., 1989). At this stage lupins can successfully compete with newly emerging weeds. Weeds are competing with the crop for water, nutrients and light; therefore effective weed control, especially during *Lupinus albus* L. early establishment, is necessary for the crop's success (Putnam et al, 1989; Poetsch, 2006).

Cultural weed control

Cultural weed control methods are practices used to improve the germination, growth and establishment of the crop, all advantages that favor the crop and not the weed (Pallut, 2000). Some practices are crop rotation, choosing the proper cultivar, optimum seeding date and seeding rate, crop fertilization, cover crop mulch etc. (Anderson, 1996). Crop rotations help to maintain a diverse microbial population in the soil, healthy soil conditions and they break pest cycles as well as reduce weed pressure (Martens and Martens, 2000). Some weeds thrive in particular crops and can be reduced by rotating with a non-favorable crop. Hence crop rotation should be diverse. In crop rotations dominated by small grain crops such as wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) annual grassy weeds will thrive. Pallut (2000) found that in rotations with only 50% small grains only 5 grassy weed plants m^{-2} were found, whereas in rotation with 100% small grains 92 weed grasses m^{-2} were found.

Lupins are successful preceding small grain crops because grain crops have can utilize the nitrogen produced by the lupins (Gesellschaft zur Förderung der Lupine, 2007). Lupins should not follow lupins in a crop rotation for at least 4 years; narrow rotations with lupins will result in yield loss by fungal diseases (i.e., anthracnose caused by fungus *Colletotrichum lupini*) (Dierauer et al., 2004; Gesellschaft zur Förderung der Lupine, 2007).

Cover crops play a major role and are beneficial in many farming systems. Some benefits are lower fertilizer costs, reduction of soil erosion and cuts in pesticide use (herbicides, insecticides, and fungicides), improved soil moisture and enhanced organic matter (Bowman et al., 1998). As a weed management tool, cover crops are used to out-compete weeds when planted as a companion. Cover crops used this way are also called smother crops and compete for light, nutrients and moisture (Anderson, 1996). Cover crops also exhibit allelopathy, which is the production of a chemical substance to inhibit the growth of other plants (Martens and Martens, 2000). In simple terms, the cover crop produces its own herbicide (Bowman et al., 1998).

Black oat (*Avena strigosa* L.), a cool-season annual cereal, is a promising new cover crop in the southern USA. Black oat was used successfully as a cover crop for soybean [*Glycine max* (L.) Merr.] in Brazil. The reason for this success is that Black oat is resistant to rust. Furthermore, Black oat can produce large biomass which helps to shade weeds and prevents soil erosion. Additionally, Black oat can control some weeds by allelopathy and break disease cycles for wheat and soybean. (Bowman et al., 1998).

Lupin can be used as a cover crop, and as a legume it provides nitrogen. Lupin cover crops are usually bitter types, which are lupin types that have an alkaloid content above 0.05%. Bitter lupins tend to be resistant to diseases and pests caused by insects and nematodes (Bowman et al., 1998).

Mechanical weed control

Mechanical weed control, also known as physical control, includes all practices that disrupt weed establishment and growth. Besides cultural weed control, mechanical weed control is the oldest weed management tool. Some practices include hand-pulling, hoeing, mowing, flooding, burning, machine tillage etc. (Anderson, 1996).

Hand-pulling and hoeing are costly in human labor and hence are usually used in high value crops or as supplement to other weed control practices. Weeds found in vegetable crops are sometimes hand-pulled and hoed. Both methods are particularly successful on weed seedlings and annual/biennial weeds (Anderson, 1996). On fields with medium or high weed pressure harrowing lupin at 10 cm high was successful. This has to be done carefully since larger plants can be damaged (George, 2005).

Mowing helps to reduce weed seed population and weed growth, but it is not very important in crop production. Flooding is used in rice production to control weeds. The weeds are basically suffocated as water displaces air from the soil (Anderson, 1996).

Manure, hay, clippings, plastic covering and other materials can be used to control weeds by excluding light from the weed plants, hence weeds cannot photosynthesize and die. Because this is an expensive weed control method it is mostly used in high value agronomic and horticultural crops (Anderson, 1996).

Burning/flaming can be divided into non-selective and selective burning. Non-selective burning is commonly used in non-crop areas, railroad right-of-ways, forestry. A directed flame near the base of the crop is selective burning. The heat of the flame inactivates enzymes and disrupts cell walls. This method requires that the crop is (much) taller than the weeds. The weed plants should not be taller than 2.5 – 5 cm. Additional control methods are usually necessary (Anderson, 1996).

Machine tillage can be divided into “primary” and “secondary” tillage. “Primary” tillage is used to prepare the seedbed. It loosens the soil 15 – 90 cm deep using various plows (i. e. moldboard and disk plow). Weed control is not a major objective of “primary” tillage, but it can bury weed seeds while inverting the soil and keep them from germinating (Anderson, 1996).

“Secondary” tillage, also called cultivation, works the soil only to a depth of 15 cm maximum, shortly before or after the planting of the crop to prepare a seedbed. Control is achieved by burial of small weeds/seedlings and up-rooting of the weed plant. Equipment used includes harrows, shovels, and rotary hoes. This method’s advantages are rapid and economical weeding of large areas with a diversity of equipment. However, there are also disadvantages and difficulties controlling weeds growing close to or between crop plants (Anderson, 1996).

Pallut (2000) found that stubble cultivation was very successful in controlling perennial weeds such as *Agropyron repens* (L.) P. Beauv. and *Cirsium arvense* (L.) Scop. (> 50%). But annual weed species were only controlled to 20% by the same procedure.

Chemical weed control

Herbicides can be grouped based on different characteristics:

1 Similarity in structure (chemical families)

2 Mode of action (Table 1.03)

3 Timing of application (pre-plant incorporated, pre-emergence, post-emergence directed or broadcast etc.)

4 Location of application (soil applied, foliar applied, over the top applied)

5 Weed species controlled

6 Crop selectivity

7 Contact or systemic herbicide (apoplastically or symplastically translocation) (Anderson, 1996).

Modes of action are grouped in alphabetical order by the Herbicide Resistance Action Committee (HRAC) (Table 1.03). Herbicides that share the same mode of action are classified in groups with one letter. There are also subclasses i.e. F_1, K_2, which indicate the different binding behavior of the herbicides on the target protein. The table also contains the numerical system of the Weed Science Society of America (WSSA) used to group herbicides.

Only a few herbicides are registered for use in *Lupinus spp*.: Aim EC (FCM) and Shark EW (FCM) with the active ingredient carfentrazone-ethyl; Cinch (DuPont) with the active ingredient S-metolachlor; Durango (Dow), Glyfos (Cheminova), Glyfos X-TRA (Cheminova), Glyphomax XRT (Dow) and Roundup Original MAX (Monsanto) with glyphosate as active ingredient (Crop Protection Reference, 2007).

Group A: Inhibition of Acetyl CoA carboxylase (ACCase)

Acetyl CoA carboxylase is important in lipid metabolism. According to HRAC (2008) two herbicide families share this mode of action, the aryloxyphenoxy-propionates (also called FOPs) and the cyclohexanediones (also called DIMs). Both herbicide families are postemergence (POST) applied, grass-active herbicides (both annual and perennial). These herbicides are considered to be "rain-fast", which means they are rapidly absorbed into the foliage of the plant. Symptoms are growth inhibition and reddening of foliage up to leaf burn (Crop Protection Reference, 2007). Another characteristic both families have in common is their rapid microbial degradation once they enter the soil. Their water solubility is between 2 ppm (FOPs) and 25 ppm (DIMs) (Wehtje, 2007).

Fluazifop-P-butyl. Fusilade DX® is a product of Syngenta Crop Protection that is registered in most of the states in the US including Alabama. This herbicide is not registered for use in lupins, but for crops as soybean and nonbearing peanut (EPA approved label). In 1989, Mitich et al. conducted a study to evaluate herbicides at three application times in grain lupin. Phytotoxicity, measured by lupin vigor, and weed control were evaluated. Weed species to be controlled were shepherds purse (*Capsella bursa-pastoris* L.), common groundsel (*Senecio vulgaris* L.), miner's lettuce (*Claytonia perfoliata* Donn ex Willd.) and desert rockpurslane [*Calandrinia ciliata* (Ruiz & Pav.) DC.]. Fluazifop-butyl was applied POST at 0.67 kg ha^{-1} and offered very poor weed control (0-53%), but the lupin vigor was only reduced moderately by the herbicide (17% vigor reduction). Fluazifop was used in a greenhouse study to evaluate its effect on white lupin (Hagemann Wiedenhoeft and Ciha, 1987). Results showed that fluazifop applied at 0.3 kg a.i. ha^{-1} POST did not reduce the shoot dry weight of white lupin. Herbicide injury on white lupin was 1%.

Sethoxydim. Sethoxydim (Poast Plus®) is a member of the DIMs. Poast Plus® is a product of Micro Flo and is registered for use in a variety of crops such as sweet corn, cotton, soybean and leguminous forage crops (Crop Protection Reference, 2007). Mitich et al. (1989) also applied sethoxydim (plus oil) at 0.45 ha ha^{-1} POST. This herbicide also led to a lupin vigor reduction of only 17%, but weed control was very poor as well (0 to 23%). This is not surprising because weed control was only measured on broadleaf species, but fluazifop and sethoxydim offer only selective grass control.

Group B: Inhibition of acetolactate synthase ALS (acetohydroxyacid synthase AHAS)

Acetolactate synthase (ASL), also called acetohydroxyacid synthase (AHAS), is the initial pathway enzyme for the production of the branched-chain amino acids valine, leucine and isoleucine. If this regulatory enzyme is blocked the synthesis of the branched-chain amino acids is inhibited. Herbicides that inhibit the synthesis of these amino acids bind to one of the four receptor sites of the ALS enzyme (Wehtje, 2007). These herbicides are therefore called ALS-inhibitors. These herbicides are grouped into four families depending on which receptor site the herbicides use. The four groups are:

- Sulfonylurea
- Imidazolinone
- Triazolopyrimidine

- Pyrimidinyl(thio)benzoate (HRAC, 2008).

ALS-inhibitors have soil as well as foliar activity with foliar acitivity being greater. These herbicides are not volatile and their water solubility varies. The use rates are very low (</= 0.22 kg ha^{-1}). Even though the herbicides show great species selectivity their symptoms are generally the same, ranging from slowing down growth to growth stoppage as well as yellowing and stunting of growth terminals (Wehtje, 2007).

Chlorimuron. Classic® with the active ingredient chlorimuron is a product of DuPont Crop Protection and is sprayed POST to selective control broadleaf weeds such as common lambsquarters (*Chenopodium album* L.), morningglories (*Ipomoea spp*.), pigweed (*Amaranthus spp*.) and yellow nutsedge (*Cyperus esculentus* L.) in soybean, peanut and non-crop areas. In Alabama as well as other southeastern states of the USA Classic® is recommended to control Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.] and bristly starbur (*Acanthospermum hispidum* DC.) in peanuts (Crop Protection Reference, 2007).

Thifensulfuron. Harmony® GT XP with the active ingredient thifensulfuron is also a product of DuPont Crop Protection for selective POST control of certain broadleaf weeds. It is registered in a wide variety of agronomic crops: wheat, barley, oat, triticale, corn and soybean (Crop Protection Reference, 2007). Some weeds controlled by Harmony® GT XP are common lambsquarters (*Chenopodium album L*.), Carolina geranium (*Geranium carolinianum* L.) and wild radish (*Raphanus raphanistrum* L.). Knott (1996) found that other members of the sulfonylurea-family for example triasulfuron, primisulfuron and metsulfuron showed variable crop injury from no crop damage to injury above the acceptable level when applied at the normal field rate and twice the normal field rate. The visible assessment of crop injury was done on a scale from 0 (= complete kill) to 10 (= no damage), where a score of 7 was still acceptable. This scale is opposite of what is normally used, where 0 would indicate no injury.

Imazethapyr. Pursuit® with the active ingredient imazethapyr is a product of BASF Corporation and is registered for use in alfalfa, clover, peas, beans, peanuts and soybean as well as Clearfield® corn (Crop Protection Reference, 2007). It can be applied either preemergence (PRE) or POST because Pursuit® shows root and foliar uptake. After absorption the active ingredient imazethapyr is rapidly translocated to the growing points of the weeds and there inhibits the weed's acetolactate synthase. Adequate soil moisture is required. Pursuit® has a broad spectrum of control. Broadleaf species controlled include: nightshades (*Solanum spp*.), ragweed species (*Ambrosia spp.)* and pigweed species (*Amaranthus spp*.). Grass weeds including johnsongrass [*Sorghum halepense* (L.) Pers.] and crabgrasses (*Digitaria spp*.) are also controlled. Additionally, Pursuit® provides nutsedge (*Cyperus spp.)* control. In a study conducted by Ivany and McCully (1994) to evaluate various herbicides for use in sweet white lupin showed that imazethapyr applied POST at 50 g a.i. ha^{-1} and 75 g a.i. ha^{-1} provided very good weed control (80 to 91%), but it also resulted in crop injury of 15 to 24% and subsequently caused yield loss. It was also mentioned by the authors that imazethapyr applied PRE resulted in good weed control and is safe to the lupin crop.

Diclosulam. Strongarm® is a product of Dow AgroSciences LLC. This herbicide is soil-applied and registered to control broadleaf weeds in peanuts in all areas of the USA except New Mexico, Oklahoma and Texas. Some broadleaf weed species controlled are tropic croton (*Croton glandulosus* L.), spurge species (*Chamaesyce spp*.) and common lambsquarter (*Chenopodium album L*.) etc. (Crop Protection Reference, 2007).

Herbicide Group C1and C2: Inhibition of photosynthesis at photosystem II

Group C1 consists of following chemical families: triazines, triazinone, triazolinone, uracil, pyridazinone and phenyl-carbamate (HRAC, 2008). Group C2 includes the chemical families: urea and amide. Herbicides in theses groups inhibit photosynthesis at photosystem II by blocking the electron transport. The herbicides bind to the proteins of the thylakoid membranes and terminate the electron transport in which electrons are removed from water and oxygen is produced.

Metribuzin. Sencor® contains the active ingredient metribuzin from Group C1. HRAC places metribuzin into the chemical family triazinone whereas Wehtje (2007) put it more generally into the triazine-family. Triazines are soil-applied and are absorbed by the roots. The chemical is translocated into the foliage where it accumulates. Sencor® is a product of Bayer CropScience and is used to control a broad range of broadleaf and grass weeds that cause problems in soybeans, potatoes, alfalfa and other crops. Some weeds successfully controlled by Sencor® are yellow nutsedge (*Cyperus esculentus* L.), nightshade species (*Solanum spp*.) etc. (Bayer CropScience Product Information, 2008).

Linuron. Linuron is an active ingredient in the urea-family and therefore belongs into group C2. Lorox® DF is a product of Griffin LLC. Lorox® DF is registered in a variety of crops: celery, hybrid poplar, parsley, potato, sorghum and soybean; but it also can be used in non-crop areas. This product can be applied PRE or POST for the control of broadleaf weeds and weed grasses. Some broadleaf weed species controlled by Lorox® DF are common ragweed (*Ambrosia artimisiifolia* L.), Florida pusley (*Richardia scabra* L.), wild radish (*Raphanus raphanistrum* L.) etc; some weed grasses controlled by Lorox® DF are fall panicum (*Panicum dichotomiflorum* Michx.), goosegrass (*Eleusine indica* L.) etc (Crop Protection Reference, 2007). Code and Reeves (1981) found that wild radish (*Raphanus raphanistrum* L.) control in lupin with metribuzin and linuron was the most effective. They found that metribuzin applied to the soil at 0.7 to 1.05 kg ha^{-1} led to a wild radish reduction of 95 to 99.5%. At the lowest rate metribuzin even reduced the weed seed production by 95 to 98%. The yield of grain lupin did not increase with the application of metribuzin. Linuron applied PRE at 3.5 kg ha^{-1} and POST at 0.3 to 0.6 kg ha^{-1} reduced the wild radish density and seed production more than 90%.

In a study done by Mitich et al. (1987) to evaluate PRE herbicides in their control of winter annual weeds in lupin it was observed that linuron applied at 2.2 kg ha^{-1} gave good control of wild mustard (*Sinapis arvensis L. spp. arvensis*), shepherd's purse (*Capsella bursa-pastoris* L.) and common chickweed [*Stellaria media* (L.) Vill.]. A linuron rate of 1.12 kg ha^{-1} gave between 30 to 75% weed control. In the same study metribuzin was applied at rates 0.28 kg ha^{-1} and 0.56 kg ha^{-1} and both rates offered 85 to 100% weed control, but the high rate also had a phytotoxicity of 79% on lupin and therefore resulted in yield loss. In a greenhouse study conducted by Hagemann Wiedenhoeft and Ciha in 1987, it was observed that metribuzin applied at 0.4 kg a.i. ha^{-1} and 1.3 kg a.i. ha^{-1} PRE visibly injured white lupin (98 to 100% injury). Ivany and McCully (1994) evaluated herbicides applied to sweet white lupin and found that metribuzin applied at a rate of 500 g a.i. ha^{-1} slightly injured the lupin plants but did not reduce the yield or the thousand seed weight. Higher rates reduced lupin yield and the thousand seed weight.

Herbicide Group E: Inhibition of protoporphyrinogen oxidase (PPO)

The inhibition of protoporphyrinogen oxidase (PPO) is the inhibition of the production of chlorophyll (Wehtje, 2007). PPO stands for protoporphyrinogen oxidase which is an enzyme that is necessary for porphyrin biosynthesis, a pathway that can be found in plants as well as animals. The porphyrin biosynthesis leads to the production of hemoglobin in animals and chlorophyll in plants. With the inhibition of this pathway a substrate of the enzyme called protoporphyrinogen IX will accumulate in the chloroplasts and later move into the cytoplasm of the cell where protoporphyrinogen IX autooxidizes to Protox IX. Protox is very photo-active. Exposed to light this pigment leads to the formation of oxygen singlets which further leads to membrane oxidation. Herbicides with this mode of action show a contact behavior due to limited translocation of the herbicide in the plant (Wehtje, 2007). According to HRAC (2008) chemical families with this Mode of Action are: diphenylethers, phenylpyrazole, N-phenylphthalimide, thiadiazole, oxidiazole, triazolinone, oxazolidinedione, pyrimidindione and other. These herbicides are used POST.

Fomesafen. Fomesafen is member of the Diphenylethers. Reflex® is only registered for use in soybean and cotton to control a variety of broadleaf weed species. Fomesafen was used in a study by Knott (1996) in which the tolerance of spring-sown lupins to various herbicides was evaluated. Crop damage was assessed by comparing treated plots with an untreated control. Lupin plants treated with a mixture of fomesafen/terbutryn at a rate of 80/200 g a.i. $litre^{-1}$ showed no damage.

Flumioxazin. Flumioxazin is in the chemical family N-phenylphthalimide. It is the active ingredient of Valor™ SX, a product of Valent U.S.A. Corporation and is registered to control weeds in cotton, peanut, soybean, sugarcane, sweet potato, fallow and non-crop areas (Crop Protection Reference, 2007). According to the Valor™ SX label, the herbicide can be applied to the soil as well as the foliage. PRE Valor™ SX applications in peanut and soybean must be made prior to crop emergence. Valor™ SX controls a wide variety of weed species including pigweed (*Amaranthus spp*.), ragweed (*Ambrosia spp*.), nightshades (*Solanum spp*.); crabgrass (*Digitaria spp*.) and panicum (*Panicum spp*.) (Crop Protection Reference, 2007).

Herbicide Group G: Inhibition of EPSP synthase

The enzyme that catalyzes the transfer of the enolpyrivyl from phosenolpyruvate to shikimate 3-phosphate (shikimic acid pathway) is 5-enolpyruvyshikimate-3-phosphate, (EPSP). EPSP synthase is a key enzyme in the production of aromatic amino acids such as phenylalanine, tyrosine and tryptophane (HRAC, 2008). There is only one herbicide that inhibits this enzyme: glyphosate (Wehtje, 2007). Glyphosate is a non-selective herbicide that is applied POST. Foliar absorption and translocation is rapid.

Herbicide Group K1: Microtubule assembly inhibition

Microtubule assembly inhibition is the inhibition of tuberin production. Tuberin is a protein that produces spindle fibers that are necessary to separate doubled chromosomes in the metaphase. This means mitosis is incomplete and cells with multiple nuclei are common (Wehtje, 2007). Symptoms are commonly observed on the root system: roots are swollen and distorted. Chemical families that inhibit this Mode of Action are: dinitroaniline, phosphoroamidate, pyridine, benzamide and benzoic acid (HRAC, 2008). These herbicides are applied PRE.

Pendimethalin. Pendimethalin is an active ingredient in the Dinitroaniline-family and is contained in Prowl® H_2O, a product of BASF Corporation. Prowl® H_2O is registered for use in a variety of crops: corn, cotton, edible beans, lentils, peas, peanuts, potatoes, soybeans etc. (Crop Protection Reference, 2007). Prowl® H_2O is a selective herbicide that controls annual weed grasses and small-seeded broadleaf weeds. Examples of weed grasses controlled are crowfootgrass [*Dactyloctenium aegyptium* (L.) Willd.], panicum species (*Panicum spp*.) and johnsongrass [*Sorghum halepense* (L.) Pers.]. Some of the broadleaf weeds controlled are common lambsquarter (*Chenopodium album* L.), pigweed species (*Amaranthus spp*.) and Florida pusley (*Richardia scabra* L.) (Crop Protection Reference, 2007). In a study for the evaluation of PRE herbicides for the control of winter annual weeds in lupin pendimethalin was applied at 1.5 lb a^{-1} and provided 85 to 100% control of wild mustard (*Sinapis arvensis L. ssp. arvensis*), shepherd's purse (*Capsella bursa-pastoris* L.) and common chickweed [*Stellaria media* (L.) Vill.], but only moderate control of annual bluegrass (*Poa annua* L.). Minor phytotoxicity of lupin was noted. Pendimethalin (0.84 kg ha^{-1}) was also applied in a combination with metolachlor (2.2 kg ha^{-1}) which provided 90 to 98% control of annual bluegrass (*Poa annua* L.), shepherd's purse (*Capsella bursa-pastoris* L.*)* and common chickweed [*Stellaria media* (L.) Vill.], but wild mustard (*Sinapis arvensis L. ssp. arvensis*) control was weak (Mitich et al., 1987). In 1989 Mitich et al. found that pendimethalin applied either preplant incorporated or PRE at 1.68 kg ha^{-1} and 2.8 kg ha^{-1} provided very good weed control (90 to 100%) and lupin tolerance was good (80 to 90% crop vigor).

<u>Herbicide Group K3: Inhibition of VLCFAs</u>

VCLFA stands for Very Long Chain Fatty Acid. This Mode of Action is an inhibition of lipid synthesis. Lipids are necessary as structural components of membranes, as part of metabolism, as coating on surfaces of organisms (cuticle) etc (Wehtje, 2007). Chemical families with this mode of action are: chloroacetamide, acetamide, oxyacetamide, tetrazolinone and other (HRAC, 2008). These herbicides are applied PRE.

S-metolachlor. Dual II Magnum®, a product of Syngenta has the active ingredient *S*-metolachlor (belongs to Chloroacetamide family). This herbicide is registered for a wide variety of crops such as corn, cotton, peanuts, pod crops and soybeans. Dual II Magnum® is used to control of annual grasses and small seeded broadleaf weeds. Some weed grasses controlled are green foxtail [*Setaria viridis* (L.) P. Beauv.], yellow foxtail [*Setaria glauca* (L.) P. Beauv.] and fall panicum (*Panicum dichotomiflorum* Michx.). Examples of broadleaf species controlled are pigweed species (*Amaranthus spp*.) and carpetweed (*Mollugo verticillata* L.) etc (Dual II Magnum® product label, 2008). Mitich et al. (1987) found that metolachlor applied at four lb a^{-1} provided very good control (90 to 98%) of annual bluegrass (*Poa annua L*.), shepherd's purse (*Capsella bursa-pastoris* L.) and common chickweed (*Stellaria media* (L.) Vill.), but control of wild mustard (*Sinapis arvensis L. ssp. arvensis*) was insufficient. In 1989 Mitich et al. observed that metolachlor applied at 2.2 kg ha^{-1} provided only poor weed control. This study also evaluated the lupin vigor and metolachlor applied at this rate reduced the crop vigor by 27%. It was found by Ivany and McCully (1994) that metolachlor applied PRE at 1680 g a.i. ha^{-1} and 2640 g a.i. ha^{-1} did not cause crop injury (0 to 5% crop injury), but the yield was reduced.

Herbicide Group O: Action-like indole acetic acid (synthetic auxins)

Herbicides that interfere with the plant's growth regulation do so by mimicing indole-3-acetic acid. Indole-3-acetic acid is an auxin, a plant growth hormone. Hence these herbicides are called action-like indole acetic acid or synthetic auxins. Since these auxins are synthetic the plant cannot regulate the herbicide induced growth, which usually is a cancer-like growth habit (Wehtje, 2007). Families with that mode of action are: phenoxy-carboxylic-acid, benzoic acid, pyridine carboxylic acid, quinoline carboxylic acid and other (HRAC, 2008). Phenoxy-carboxylic-acids selectively control broadleaf weeds in grasses and are applied POST. Another member of this chemical familyis 2,4-DB, which offers broadleaf weed control in legume crops such as alfalfa, clover, soybean and peanut.

Herbicide options in lupin

Hagemann Wiedenhoeft and Ciha (1987) found that the POST applied 2,4-DB ester at two rates (0.8 kg ha^{-1} and 2.4 kg ha^{-1}) at the 1-2 leaf stage and 4-5 leaf stage showed different results. Both rates applied at the 1-2 leaf stage injured white lupin to 99 to 100%, whereas the rates applied at the 3-4 leaf stage only injured white lupin to 59 to

73%. Knott (1996) also investigated the tolerance of fall-sown determinate lupins to herbicides. He observed that lupins are sensitive to many POST herbicides. The most promising treatments found by Knott (1996) were a combination of isoxaben and trifluralin PRE, a mixture of isoxaben and terbuthylazine as well as the treatment with simazine early POST. He also found that spring applications of primisulfuron or triasulfuron are promising.

Experimental Objectives

The purpose of this experiment was to explore the effects of weed management practices on white lupin performance and weeds. We wanted to explore if herbicides that are currently registered in other leguminous crops could be used successfully in white lupin. Additionally this experiment was investigating non-chemical weed control practices:

- Two mechanical practices: between or between and within row hoeing
- Cultural practices: two black oat cultivars as a companion crop.

The main objectives were:

1. To investigate the use of various herbicides and weed management practices in white lupin and evaluate their effect on weed control.
2. To investigate the use of various weed management practices and evaluate their effect on white lupin injury, plant density and yield.
3. To investigate the use of various weed management practices and evaluate their effect on white lupin yield components.

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Table 1.01: Soil and Climate requirements of *Lupinus* ssp. (Gesellschaft zur Förderung der Lupine, 2007)

Species	Soil	Climate
L. luteus (Yellow Lupin)	Sands and weak loamy sands with low pH (4.6 – 6.0); higher pH-values lead to lime induced chlorosis (chlorosis of the youngest leaves), Yield potential: 15 to 20 dt ha-1	Moderate temperatures during vegetative development, dry weather during maturity; vegetation days: 135 to 150 days (depends on cultivar)
L. angustifolius (Narrow-leaf Lupin)	Sands, sandy loams; more lime tolerant than Yellow Lupin; optimum pH-values: 5.0 to 6.8; no moor- or heath land (Yellow Lupin better adapted), Yield potential: 20 to 45 dt ha-1	Suitable for areas with short vegetation period; foothills, coastal areas; vegetation days: 120 to 150 days (depends on cultivar)
L. albus (White Lupin)	Highest yield on better soils (sandy loam minimum, better loamy loessic soils, topsoils); also sands with pH 5.5 to 6.8; no pH-values above 7, Yield potential: 20 to 60 dt ha-1	Warm, moist spring; high yields require cool temperatures until begin of length growth as well as good water service until blooming

Table 1.02: Protein, oil, energy and typical yield of field beans, peas and lupins (dry grain) (Putnam, D. H. et al 1989).

	Field beans	Spring beans	White lupin	Blue lupin	Yellow lupin
Protein (%)	22.5	25	36 – 40	31 – 35	34 – 42
Oil content (%)	1.9	1.8	10	6	4
Energy ME (MJ/kg DM)	13.5	12 – 13.5	15.5	13.5	13
Yield $Mg\ ha^{-1}$	3.5	2.8	3.5	2.5 – 3	2.5 – 3
pH tolerance	5.9 – 6.5	6.5 – 7.5	5.0 – 7.9	5.0 - 7	4.8 - 7

Table 1.03: Alphabetical order of Mode of Action used in this study based on the order by the Herbicide Resistance Action Committee (www.plantprotection.org/hrac).

HRAC	WSSA Group	Mode of Action
A	1	Lipid synth. Inh. (inh. of ACCase)
B	2	Inhibition of ALS (branched chain amino acid synth.)
C	5,6,7	Inhibition of photosynthesis PS II
E	14	Inhibition of protoporphyrinogen oxidas
G	9	Inhibiton of EPSP syhnthase
K1	3	Inhibition of microtubule assembly
K3	15	Inhibition of cell division
O	4	Synthetic auxins

II. EVALUATION OF WEED MANAGEMENT PRACTICES ON WEED CONTROL IN WHITE LUPIN (*LUPINUS ALBUS L.*)

Abstract

Worldwide, 450 lupin species can be found with four agronomical important species currently grown. The major species consist of the three old world species white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.) and narrowleafed or blue lupin (*L. angustifolius* L.) and the new world species Andean lupin (*L. mutabilis* Sweet). White lupin is of major interest in the southeastern USA because winter-hardy varieties are available. Winter-type *Lupinus albus* L. cultivars can be used in winter grain rotations and as mid-winter forage for ruminants. White lupins are poor weed competitors during early establishment, which makes effective weed control necessary. A study experiment was conducted at two sites at E.V. Smith Research Center of the Alabama Agricultural Experiment Station in 2007 and 2008. The weed management schemes evaluated included ten pre-emergence (PRE) and nine post-emergence (POST) herbicide treatments as well as cultural treatments (two mechanical and two companion crop living mulch weed control measures). Fourteen weed species were encountered. Of the PREs, the three application rates of pendimethalin (0.5x, 1x, 2x) controlled shepherd's purse (*Capsella bursa-pastoris* (L.) Medik.) more than 80%. *S*-metolachlor gave overall >80% weed

control, but yellow nutsedge (*Cyperus esculentus* L.) was only controlled to 73%. Wild radish (*Raphanus raphanistrum* L.) was controlled to 98% by a *S*-metolachlor/linuron mixture. Metribuzin gave more than 90% wild radish control. The PRE and POST applied imazethpyr gave a mean weed control of more than 80%. Glyphosate was one of the best POST applications with a non-selective weed control of more than 80%. Annual ryegrass (*Lolium multiflorum* Lam.) was controlled to more than 95% by sethoxydim and fluazifop (POST each). Black oat (*Avena strigosa* Schreb.) provided more than 90% control of annual ryegrass, shepherd's purse and yellow nutsedge. The mechanical weed control measures, hoeing, provided more than 80% control of annual bluegrass (*Poa annua* L.), shepherd's purse and crimson clover (*Trifolium incarnatum* L.).

Introduction

Lupin (*Lupinus ssp* L.) belongs to the botanical family of *Fabaceae* and originated in three primary centers; North America, South America, and the Mediterranean region (Wilbur, 1963; Wink et al., 1999, Noffsinger and van Santen, 2005). Worldwide, 450 lupin species can be found of which four major species are used agronomically (Dierauer et al., 2004). The major economically important species consist of the three old world species white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.) and narrowleafed or blue lupin (*L. angustifolius* L.), and the new world species Andean lupin (*L. mutabilis* Sweet).

White lupin was first introduced into the southeastern United States in the 1930s and the production eclipsed 1 million ha in the early 1950s, then declined due to loss of government support for green manuring, damage to seed nurseries due to mid-autumn freezes in two consecutive years and the increased availability of inorganic nitrogen fertilizers (Payne et al., 2004; van Santen and Reeves, 2003; Noffsinger and van Santen, 2005). *Lupinus albus* L. is of major interest in the southeastern USA because accessions and cultivar exhibit differential vernalization requirements similar to what is common in wheat (*Triticum aestivum* L.). Winter-type cultivars offer a commercial opportunity for farmers. It was shown that white lupin used in a winter grain rotation increased lint yield in cotton (*Gossypium hirsutum* L.) as compared to traditional rotations (Noffsinger and van Santen, 2005). Furthermore, *L. albus* L. is attractive as mid-winter forage for ruminants due to a forage quality similar to that of alfalfa (*Medicago sativa* L.) (Noffsinger and van Santen, 2005). Additional benefits of white lupin winter-type cultivars may be better disease resistance. Historically and today, white lupin is used as livestock feed and human food as well as winter cover crop in conservation agriculture (Hill, 1990; Hill, 2005; Noffsinger and van Santen, 2005).

Lupinus spp. are poor weed competitors during early establishment, since canopy development is slow, facilitating light penetration and subsequent weed seed germination and yield loss due to competition. Lupins reach their maximum vegetative growth during flowering (Putnam et al., 1989). At flowering, lupins can successfully compete with newly emerging weeds. Weeds are competing with the crop for water, nutrients and light; therefore effective weed control, especially during *Lupinus albus* L. early establishment, is necessary for the crop's success (Putnam et al., 1989; Poetsch, 2006).

Research has been conducted to compare the herbicide efficacy in lupin. Chambers et al. (1995) investigated the effectiveness of aryloxyphenoxypropionate (fop) and cyclohexanedione (dim) herbicides on controlling annual ryegrass (*Lolium multiflorum* Lam.) and volunteer cereals such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) and oat (*Avena sativa* L.) in *Lupinus angustifolius* L. Results showed that fluazifop and sethoxydim of the previously mentioned herbicide families gave >98% control of wheat (*Triticum aestivum* L.), triticale (x *Triticosecale* Wittm ex A. Camus) and annual ryegrass (*Lolium multiflorum* Lam.). The dinitroaniline family preemergence (PRE) herbicide pendimethalin, registered for control of annual grass and broadleaf weeds, controls Russian thistle (*Salsola tragus* L.) and prostrate knotweed (*Polygonum aviculare* L.) 100% in white lupin (Ball, 1992). Wild mustard (*Sinapis arvensis* L.), shepherds purse [*Capsella bursa-pastoris* (L.) Medik.] and common chickweed [*Stellaria media* (L.) Cyrillo] were controlled 85 to 100% in spring-type white lupin (Mitich et al., 1987). Chloroacetamides such as metolachlor and alachlor which are applied PRE usually in mixes with other herbicides successfully controlled annual grasses and some broadleaf weed species >90% in spring-type white lupin (Mitch et al., 1987; Penner et al., 1993). Imazethpyr when applied PRE and postemergence (POST) provided good broadleaf weed control (> 80%) in sweet white lupin (Ivany and McCully, 1994). Wild radish (*Raphanus raphanistrum* L.) is difficult to control in lupin production but Code and Reeves (1981) found that triazines such as metribuzin controlled this weed by 95 to 99.5% when applied PRE.

Hoeing is prohibitive due to labor cost and hence is only used in high value crops or as supplement to other weed control practices and is successful on weed seedlings and annual/biennial weeds (Anderson, 1996). This mechanical weed control practice is important in organic production which is an increasing sector in US agriculture. To be certified as organic a farm has to follow the guidelines of the National Organic Program (NOP) from the seeds used to grow the crops to the final product. The NOP is a program developed by the United States Department of Agriculture and limits the use of synthetic herbicides; therefore other weed control practices such as hoeing are necessary (Cornell Cooperative Extension Publication, 2009).

Cover crops play a major role and are beneficial in any farming system such as conservation agriculture and organic farming. Some benefits are lower fertilizer costs, reduction of soil erosion, cuts in pesticide use (herbicides, insecticides, and fungicides), improved soil moisture, enhanced organic matter and breaking of pest cycles (Bowman et al., 1998). As a weed management tool, cover crops are used to out-compete (smother) weeds or by allelopathy (Anderson, 1996). Black oats (*Avena strigosa* Schreb.), a cool-season annual cereal, is a promising new cover crop in the southern USA and has been used successfully for many years as a cover crop for soybean [*Glycine max* (L.) Merr.] in Brazil (Bowman et al., 1998). Reasons for the success of this cover crop are its large biomass production and its exceptional allelopathic activity (Price et al., 2008). Both are very important for non-chemical weed control.

Only three active ingredients are currently registered for the use in lupins; carfentrazone-ethyl, *S*-metolachlor and glyphosate (Crop Protection Reference, 2007). Therefore, the objective of this experiment is to investigate the use of various herbicides and weed management practices in white lupin and evaluate their effect on weed control.

Materials and Methods

A two year experiment to investigate the effect of weed management practices on weed control in *L. albus* L. was established at two test sites on the E.V. Smith Research Center of the Alabama Agricultural Experiment Station in October 2007 and 2008 respectively.

Treatment and experiment design

The experiment had a 2 (year) x 2 (location) x 3 (cultivar) x 4 (block) x 24 (weed control) factorial arrangementof treatment and design factors. The two locations of the experiment were the Field Crops Unit (FCU), near Shorter, AL (32.42 N, 85.88 W) and the Plant Breeding Unit (PBU), Tallassee, AL (32.49 N, 85.89 W). At FCU the experiment was established on a Compass loamy sand (a coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults with a loamy sand surface structure). At PBU the experiment was conducted on a Wickham sandy loam (a fine-loamy, mixed, semiactive, thermic Typic Hapludults with a sandy loam surface structure). The three cultivars used in the experiment were AU Homer (a high-alkaloid, indeterminate cover crop type), AU Alpha (a low-alkaloid, indeterminate forage type), and ABL 1082 (low-alkaloid, determinate grain type experimental cultivar). The experimental design was a randomized complete block design (r = 4) nested within each year x location x cultivar combination. The weed control factor had 24 levels: one non-treated control, 10 PRE-applied herbicides, nine POST-applied herbicides, two mechanical (hand hoed) weed control treatments as well as two cultural (living mulch) weed control treatments (Table 2.01).

Crop management

Inoculated lupin was seeded in 4 row plots with a John Deer® 1700 four row vacuum planter with a row spacing of 90 cm at a depth of 1.25 cm in October 2007 and October 2008. Seeding density was 19 seeds m^{-1}. A smooth seedbed was prepared one to two weeks prior to planting in 2007. In 2008, the cultivars were planted in raised beds prepared by a KMC 4 row ripper/bedder due to concerns about water logging at both locations. The plot length was 7.5 m at PBU, and 7.5 m and 6 m at FCU in 2007 and 2008, respectively. The PRE herbicide treatments were applied one day after planting in both years. Application of POST herbicides followed 13 (2007) to 16 (2008 due to heavy rainfall) weeks after planting. The cultural control treatments, cv. SoilSaver and As_033 (a selection from PI 436103) black oat (*Avena strigosa* Schreb.), were sown one (2007) to seven days (2008) after seeding of the lupin crop. The mechanical weed control treatments, between row only cultivation and between and within row cultivation, were used twice four (2007) to six (2008) weeks after planting and 18 to 20 (2 blocks at the PBU test site due to heavy rains) weeks after planting.

Ratings

Weed control ratings were taken at both locations on a scale from 0% to 100%, where 0% is equivalent to no control and 100% is equivalent to complete weed control. Three weed control ratings per treatment/plot were taken in each year of the study. Each treatment was rated based on the present weed infestation in the non-treated control of the first block at each location. The non-treated control was considered to have 0% weed control. In study year 2007/2008 the first rating was taken after only the PRE herbicide treatments were applied (6 weeks after PRE application), the second and third rating were taken 6 and 9 weeks after the POST treatments were applied. The following study year (2008/2009) the first two ratings were taken 6 and 10 weeks after the PRE herbicide treatments were applied, and one rating was taken 5 weeks after the POST treatments were applied.

Statistical analysis

Generalized linear mixed models procedures as implemented in SAS® PROC GLIMMIX were used to analyze weed control data. This tool is flexible in the analysis of data with non-normal distribution and unbalanced designs. Violations of normality and homogeneity of variance issues are often encountered when including a non-treated control treatment or percent control data with a large range. Weed control data were modeled using a binary distribution function or arcsine transformed data. All treatment factors and their interactions were considered fixed effects except the block factor and its interaction with the various treatment factors. Whenever a given species occurred in more than one environment, a combined analysis was used. Statistical significance was declared at Dunnett's $P < 0.1$.

Results

Observed weed species

Over the course of the two-year study 14 weed species were observed. Not all species were present in all environments, thus Tables 2.02 and 2.03 give the percent of plots at a given rating that contained the weed species in question. In 2007 and 2008, henbit, a winter annual species, was present at PBU (100%) when rated after the PRE application, but was absent at the POST rating. Corn spurry, an annual broadleaf species, was encountered at both locations and in both years at the POST rating. At PBU in 2008 however, it was also present at the PRE rating, but its presence was less than 75% in all three cultivars at each rating. Corn spurry presence was 100% in lupin cultivars AU Alpha and AU Homer and 75% in cultivar ABL 1082 in each rating at this location in 2007. Winter vetch (75-100%) and wild radish (75-100%) were primarily encountered in the POST rating at FCU and PBU in 2007. In 2008, winter vetch was present in 75 to 100% of the FCU plots when rated after the POST application. Cutleaf-evening primrose was present in 100% of the plots during the POST rating at both locations in 2007. In study year 2008 this weed was again only present at the POST application rating in 75% of the plots at FCU in which lupin cultivar AU Alpha was grown, but was present to 100% in the remaining FCU and PBU plots. Heartwing sorrel was present in 100% of the plots at FCU at the POST rating in 2007 and 2008, but was not present at the PRE rating at this location in either year. In 2008, this weed species was encountered in 100% of the plots at PBU when rated after the PRE application. Shepherd's purse was present in 100% of the plots at both locations at the POST rating in 2007. In 2008 when rated after POST application, this weed species was absent in all FCU plots and in PBU plots in which lupin cultivar ABL 1082 was grown. But shepherd's purse was present in 50% and 100% of the plots containing cultivars AU Alpha and AU Homer respectively. Annual ryegrass was only present in 50% to 100% of the plots at both locations at the POST rating in study year 2007. Yellow nutsedge was present in study year 2007 only. At PBU it was observed in 100% of the plots at the POST rating. Black medic was present in 50 to 83% (POST rating) of the FCU plots in 2008 only. Annual bluegrass and lesser swinecress were observed in 100% of the plots at PBU at both ratings in 2008. Carolina geranium was only present in 100% of the PBU plots at the rating after POST application in 2007. Similarly, Crimson clover was only observed at the POST rating in 2007. This clover species was present in 100% of the PBU plots and in 100% of the FCU plots in which cultivars AU Alpha and AU Homer were grown. Only 75% of the FCU plots with cultivar ABL 1082 had crimson clover present.

Species present in only a single environment

Black medic. Black medic (*Medicago lupulina* L.) was present at FCU at the POST rating in study year 2008 only. Only the treatment main effect was significant ($p<0.1$). Results varied from 27% to 99% mean weed control by the PRE herbicides, from 38% to 98% control by the POST herbicides and from 42% to 92% by organic weed control methods. As can be seen in Table 2.04 the mean control of all treatments was significantly better than the non-treated control, with the exception of the PRE applied imazethapyr treatment (27% control). In general the PRE herbicide treatments, providing 66-99% control (imazethapyr excluded), were more successful in control than the POST treatments. The most successful PRE treatments were flumioxazin (99%), the *S*-metolachlor/linuron mixture (98%), diclosulam (97%) and the highest rate of pendimethlin (96%). The POST directed applied glyphosate provided best mean control (98%) of all POST treatments, followed by 2,4-DB with 86%. Mean weed control of the organic treatments varied greatly (42-92%). Between and within row cultivation provided 92% control as compared to 82% control with between row cultivation only. At this rating SoilSaver black oat provided only 42% as compared to 54% control by As_033 black oat.

Lesser swinecress. In 2008, lesser swinecress [*Corononpus didymus* (L.)Sm.], the second single environment species, was present at both ratings at PBU. Treatment effects were significant. At the first rating after PRE application 17 to 99% of lesser swinecress control was achieved (Table 2.05). All PRE herbicide treatments provided control of this species that was significantly better from the non-treated control group. Flumioxzin and diclosulam provided best control of this species of all the PRE applied herbicide treatments with 99% and 98% control respectively, followed by metribuzin (96%) and imazethapyr (95%). Of all the PRE treatments the three rates of pendimethalin provided the least control. The lowest pendimethalin rate controlled this species to 45%, the field rate to 41% and the highest rate to 78%. Best mechanical weed control was achieved by between and within row cultivation with 84%, followed by between row cultivation (73%). At the PRE rating both black oat cultivars provided poor control, SoilSaver with 17% and As_033 with 18%. Their mean control was non-significant when compared to the non-treated control group. At the POST rating all PRE herbicide treatments provided successful lesser swinecress control that was significantly better from the non-treated control. Best control of this species was achieved by the PRE-applied flumioxazin (95%), diclosulam (94%), *S*-metolachlor/linuron (94%) and linuron alone (93%). The three pendimethalin treatments again provided the least control with 39%, 46% and 71% respectively. The POST-applied herbicide treatments were not as uniformly successful in control as the PRE-applied. Best control was achieved by glyphosate with 92%. The POST-applied imazethapyr provided a mean control of 85%. Least control was achieved with fluazifop (5%), plant oil (7%) and the POST-applied flumioxazin (10%). These treatments provided control that was non-significant when compared to the non-treated control. All organic treatments provided significantly higher mean control than the control group. Nonetheless control of lesser swinecress by both black oat cultivars was poor, SoilSaver with 47% and As_033 with 27%. Between and within row cultivation is the most successful mechanical weed control method for this weed with 95% mean control, followed by between row cultivation with 76% mean control.

Annual bluegrass. In 2008, annual bluegrass (*Poa annua* L.) was present at both ratings at PBU. All PRE treatments as well as the organic treatments provided significantly higher mean bluegrass control (32-98%) than the non-treated control group (4%) at the PRE rating (Table 2.06). Best control was achieved with linuron (98%), flumioxazin and diclosulam (both 97%) and metribuzin (96%). Of all the PRE herbicide treatments the lowest rate of pendimethalin provided the least control with 86% at the first rating. Black oat cultivar As_033 controlled annual bluegrass to only 32%, whereas SoilSaver controlled to 56%. This is nonetheless significantly improved from the non-treated control. Between and within row cultivation provided slightly better control (74%) than between row cultivation (68%) at the first rating. Control was not as good at the POST rating. All PRE herbicide treatments provided control of 13 to 93% which is significantly different from the non-treated group at this rating. Best control by PRE herbicides was achieved by *S*-metolachlor with 93%, *S*-metolachlor/linuron with 92% and the field rate of pendimethalin with 82%. Diclosulam and PRE-applied imazethpyr provided the poorest control at the POST rating with 13% and 4% control, respectively. The POST applied herbicides achieved control that varied greatly (0% to 81%). All POST herbicide treatments showed significantly better mean control in comparison to the non-treated control, with the exception of the POST -applied imazethapyr. Best species control was achieved by glyphosate with 81% and the grass active herbicides fluazifop and sethoxydim, both with 66%. At the POST rating, both black oat cultivars controlled annual bluegrass successfully to 87% (As_033) and 88% (SoilSaver). Between and within row cultivation control (87%) was better than between row cultivation only (61%).

Carolina geranium. Carolina geranium (*Geranium carolinianum* L.) was present only at the POST rating at PBU in 2007. The two-way interaction (treatment*cultivar) was non-significant, but treatment main effect was significant. All herbicide treatments as well as the organic treatments used in this experiment provided mean control that was significantly better from the non-treated (Table 2.07). Mean weed species control ranged from 89% to 99% by the PRE herbicides, from 80% to 97% for the POST herbicides and from 93% to 98% for the organic treatments. Best control by a PRE herbicide treatment was provided by the *S*-metolachlor/linuron mixture with 99% control, followed by metribuzin with 98%, *S*-metolachlor with 96%, flumioxazin with 96% and imazethapyr with 95%. With 89% control the field rate of pendimethalin performed the worst of all PRE treatments. Best control by a POST herbicide treatment was achieved by thifensulfuron with 97% control, followed by 2,4-DB with 94% and imazethapyr with 91% control. Chlorimuron controlled Carolina geranium to 67% and therefore performed worse than any other POST. Both black oat cultivars, controlled to 98%. The mechanical control treatment, between and within row cultivation, with 97% control was slightly more efficient than between row cultivation (93%) only.

Yellow nutsedge. Yellow nutsedge (*Cyperus esculentus* L.) was present at the POST rating at PBU in 2007 only. Treatment effect was significant. All chemical and organic weed control treatments provided significantly higher weed control than the control (Table 2.08). Mean control achieved by all PRE herbicide treatments varied from 67% to 97%. All POST herbicides controlled 80% to 97%. The organic treatments provided 78% to 99% control. Best control by a PRE herbicide was shown by all three pendimethalin application rates with 97%, 95% and 90% (from low to high rate) respectively. *S*-metolachlor (97%) and flumioxazin (91%) are equally successful. Diclosulam only provided 67% control and was therefore the least successful PRE herbicide to control this weed. In the POST herbicide group, best control was provided by the grass active herbicides sethodxydim (97%) and fluazifop (94%), followed by 2,4-DB (93%) and imazethapyr (91%). With 80% and 82% weed control, chlorimuron treatment and thifensulfuron were the least successful POST treatments. Yellow nutsedge was successfully controlled by all four organic treatments. Both black oat cultivars provided 99% control. Between and within-row cultivation with 86% performed slightly better than between row cultivation (78%).

Henbit. In 2007 and 2008 henbit (*Lamium amplexicaule* L.) was present only at the PRE rating at PBU. Treatment effect was significant in both years. The two-way interaction (treatment*cultivar) was significant in 2007. All PRE herbicide treatments were significantly better in controlling this species than the non-treated control in both years (Table 2.09). In 2007, mean weed control by PRE herbicides varied from 90% to 99%. Best control was provided by the *S*-metolachlor/linuron mixture (99%) and diclosulam (99%). All three pendimethalin application rates controlled henbit 97% (low rate) and

99% (field rate and highest rate). With 90% mean control *S*-metolachlor alone was the least successful PRE herbicide that year. None of the organic weed control options provided significantly better control than the non-treated control in 2007. Between-within row cultivation and between row cultivation provided 5% control. SoilSaver was the better performing black oat cultivar with provided 49% control, followed by As_033 with 26% control.

In 2008, the results were similar. All PRE herbicide applications significantly reduced henbit infestation as compared to the non-treated control. Henbit was controlled best by the PRE-applied flumioxazin and imazethapyr (both 99%), followed by diclosulam (98%), the highest rate of pendimethalin (98%), the field rate of pendimethalin (97%) and *S*-metolachlor (97%). Linuron, with 86% mean control, was the least successful PRE herbicide that year. In 2008, both mechanical weed control methods provided significantly better control than the non-treated control. Between and within row cultivation controlled this weed species to 73%, followed by between row cultivation with 49%. With 3% and 7% control, black oat cultivars As_033 and SoilSaver did not reduce the henbit population at PBU significantly.

Species present in multiple environments

Crimson clover. Crimson clover (*Trifolium incarnatum* L.) was present at FCU and PBU at the POST rating in 2007 only. Two-way interaction treatment*cultivar was only significant at FCU. Treatment effect was significant at both locations. At both locations all chemical and organic treatments provided significantly higher control than the non-treated control (Table 2.10). At FCU mean control of PRE herbicides varied from 47% to

99%. Best control was achieved by the *S*-metolachlor/linuron mixture (99%), metribuzin (99%), linuron (98%), diclosulam (98%) and flumioxazin (98%). With 47% mean control imazethapyr was the least successful PRE herbicide to control this species, followed by the field rate of pendimethalin (78%). The mean control by POST herbicides varied from 48% to 98% at FCU. With 98% control the chlorimuron treatment provided best control, followed by glyphosate with 92% control and flumioxazin with 89% control. 2,4-DB, sethodxydim and imazethapyr were the least successful POST herbicide treatments with 48%, 50% and 64% control, respectively. Between and within row cultivation as well as between row cultivation were equally successful to control crimson clover (>90%). The black oat cultivar As_033 with 85% control was slightly more successful than SoilSaver (73%).

At PBU, all chemical and organic treatments controlled crimson clover significantly better than the non-treated control (Table 2.10). All PRE herbicides uniformly provided 99% control. Similarly all POST herbicides controlled to 99%, with the exception of fluazifop and 2,4-DB with 98% control each. 98% to 99% control was also achieved by the four organic treatments.

Wild radish. Wild radish (*Raphanus raphanistrum* L.) was present at FCU and PBU at the POST rating in 2007. Two-way interaction treatment*cultivar was only significant at FCU. Treatment effect was significant at both locations. At both locations all chemical and organic treatments provided significantly better control than the non-treated control (Table 2.11). At FCU, mean control by PRE herbicides varied between treatments (63% to 98%). Best control was achieved by diclosulam and the *S*-metolachlor/linuron mixture (both 98%), followed by flumioxazin and highest rate of pendimethalin (96%). With 63%

control the lowest rate of pendimethalin was the least successful of all PRE herbicides at FCU. The POST herbicides controlled this species 43% to 99%. Best control by a POST herbicide was provided by chlorimuron and fomesafen with 99% control each. With 43% and 57% control respectively, fluazifop and glyphosate were the least successful POST herbicides at this location. Between and within row cultivation and between row cultivation with >90% control were the better organic weed control treatments than both black oat cultivars with less than 80% weed control.

Similar results were observed at PBU. At this location wild radish was controlled >94% by PRE herbicides, >90% by POST herbicides and >95% by organic weed control methods. Best control by a PRE herbicide was provided by the *S*-metolachlor/linuron mixture, linuron, diclosulam, imazethapyr and the highest application rate of pendimethalin (all 99%). Of all the POST herbicides fomesafen, chlorimuron and imazethapyr reduced wild radish at PBU better than other POST herbicides. Between and within row cultivation and the black oat cultivar As_033 (with <96%) were slightly better in controlling this species than the other organic weed control methods.

Shepherd's purse. In 2007, shepherd's purse (*Capsella bursa-pastoris* L.) was present at the POST rating in FCU and PBU, but was only present at the POST rating at PBU in 2008. In 2007, all chemical and organic weed control treatments were significantly better at both locations than the non-treated control (Table 2.12). At FCU the PRE herbicides provided 89% to 99% control. With 89% control imazethapyr is the least successful PRE herbicide. The POST herbicides provided 97% to 99% control. Chlorimuron and 2,4-DB (both 99%) controlled shepherd's purse the best at FCU. Of the organic treatments, both black oat cultivars provided 99% control followed by between-within row cultivation and between row cultivation at this location.

At PBU 2007, the PRE herbicides controlled shepherd's purse < 90%. The lowest rate of pendimethalin with 90% control was the least successful PRE herbicide. The POST herbicides provided also >90% control. Best control was achieved by thifensulfuron, chlorimuron and glyphosate each with 99% control. The least successful POST herbicide was 2,4-DB (90%), followed by sethoxydim and flumioxazin (both 91%). All organic weed control methods provided 99% control, with the exception of between and within row cultivation (98%).

In 2008, control of shepherd's purse varied greatly between treatments. The PRE herbicides controlled this weed 3% to 99%. With 99% control diclosulam provided best control followed by flumioxazin. The lowest application rate of pendimethalin only controlled to 3% and was therefore the least successful PRE herbicide. The half rate and the field rate of pendimethalin as well as *S*-metolachlor provided no significantly better control than the non-treated control. The POST herbicide treatments controlled 21% to 96%. With 96% control glyphosate was the best POST herbicide at PBU in 2008, followed by fomesafen (94%). 2,4-DB, plant oil, fluazifop and sethoxydim (<36%) provided no significantly better control than the non-treated control. Both black oat cultivars show significantly better control than the non-treated control group. Both cultivation treatments control shepherd's purse to >93%.

Annual ryegrass. Annual ryegrass (*Lolium multiflorum* Lam.) was present at the POST rating at FCU and PBU in 2007. Treatment effect was significant. All chemical and organic treatments provided significantly better control than the non-treated control

(Table 2.13). At FCU, the PRE treatments provided >95% control. Best control was achieved by the highest rate of pendimethalin (99%), followed by the *S*-metolachlor/linuron mixture, linuron and *S*-metolachlor (all 98%). The POST herbicides provided >93% control at FCU. Best control by a POST herbicide was provided by glyphosate and sethoxydim (both 99%), followed by fluazifop (98%). The organic treatments controlled annual ryegrass to >95%.

At PBU, the PRE treatments provided 58% to 97% control. Best control was achieved by the *S*-metolachlor/linuron mixture (97%), followed by *S*-metolachlor (93%) and linuron (90%). The low rate of pendimethalin controlled this weed species to 58% and was therefore the least successful PRE herbicide. The POST herbicides controlled annual ryegrass 64% to 99%. Best control was achieved by the grass active herbicides fluazifop and sethoxydim with 99% and 96% control, respectively. Thifensulfuron (64%) and chlorimuron (65%) provided least control of all the POST herbicides at PBU. Organic weed control methods provided 79% to 93% control. Between-within row cultivation (93%) was more successful to control this species than between row cultivation (79%). Black oat cultivar SoilSaver (88%) controlled annual ryegrass slightly better than As_033 (81%).

Cutleaf-evening primrose. Cutleaf-evening primrose (*Oenothera laciniata* Hill) was present in at the POST rating at FCU and PBU in 2007 and 2008 (Table 2.14). Treatment effect was significant. Treatment*cultivar interactions was only significant at PBU 2007. At FCU in 2007, control of cutleaf-evening primrose by PRE herbicide varied from 23% to 97%. Best control was provided by flumioxazin (97%), followed by diclosulam (96%) and metribuzin (94%) which is significantly better than the non-treated control. The field application rate of pendimethalin (23%) provided no significantly higher control than the non-treated control. The POST herbicides provided 15% to 98% control at FCU in 2007. Best control was achieved by 2,4-DB and chlorimuron (both 98%), followed by flumioxazin (93%), which is significantly better compared to the non-treated control. With 15% control thifensulfuron was the least successful POST treatment at FCU in 2007. This herbicide showed no significant improvement to the non-treated control. With 95% and 96% black oat cultivars As_033 and SoilSaver successfully controlled cutleaf-evening primrose. Between-within row cultivation with 80% control performed better than between row cultivation (58%). All of the organic treatments significantly improved mean control as compared to the non-treated control at FCU in 2007.

At PBU in 2007 all chemical and organic weed control methods, with the exception of the PRE-applied field rate of pendimethalin (14% control), showed significantly better control than the non-treated control. PRE herbicides controlled this species 14% to 95%. Best control by a PRE was provided by flumixoazin and *S*-metolachlor/linuron (both 95%), followed by diclosulam (94%) and imazethapyr (92%). POST herbicides controlled cutleaf-evening primrose 31% to 99%. Best control was provided by 2,4-DB (99%), followed by chlorimuron (98%) and flumioxazin (88%). With 31% weed control thifensulfuron was the least successful POST herbicide treatment at PBU in 2007. The organic treatments controlled this species 74% to 98%. Both black oat cultivars provided 98% control. Between and within row cultivation (88%) provided 88% control as compared to between row cultivation alone (74%).

At FCU in 2008, mean control by PRE herbicide treatments ranged from 10% to 94% (Table 2.14). All PRE herbicide treatments, with the exception of all three application rates of pendimethalin (30%, 10%, 23% from low to high rate), significantly reduced cutleaf-evening primrose infestation as compared to the non-treated control. Best control by a PRE was provided by flumioxazin with 94% control, followed by diclosulam and linuron (both 85%). The POST herbicide treatments controlled this species 39% to 95% at FCU in 2008. All POST herbicide treatments provided significantly better control than the non-treated control. With 95% control glyphosate performed best of these POST herbicides, followed by 2,4-DB, imazethapyr and flumioxazin (>80%). Fomesafen (41%) and sethoxydim (39%) were the least successful POST herbicides. The organic weed control treatments controlled this species 43% to 92% at FCU in 2008. Both black oat cultivars, SoilSaver and As_033 with <60%, were less successful in controlling this species than the cultivation treatments (>80%).

Similar results were observed at PBU in 2008. PRE herbicides controlled cutleaf-evening primrose 6% to 96%. Best control by a PRE herbicide was provided with imazethapyr with 96% control, followed by flumioxazin (95%) and diclosulam (91%). All three application rates of pendimethalin with less than 12% control as well as *S*-metolachlor alone (12%) did not control this species significantly better than the non-treated control. Weed control by POST herbicide application ranged from 14% to 96%. All POST herbicide treatments significantly improved control as compared to the non-treated control. With 96% control each, 2,4-DB and imazethapyr provided best control by POST herbicides, followed by glyphosate with 91% control. The plant oil treatment (14%), sethoxydim (25%) and fluazifop (28%) were the least successful POST herbicides at PBU in 2008. Again the organic weed control methods provided cutleaf-evening primrose control that was significantly better than the non-treated control. As_033 with

63% control performed better than SoilSaver with 35% control. Between and within row cultivation (92%) was the better cultivation treatment at PBU in 2008.

Winter vetch. Winter vetch (*Vicia villosa* Roth) was present at the POST rating at both locations in 2007 and at FCU in 2008. Treatment effect was significant in both years. All treatments significantly reduced winter vetch infestation as compared the non-treated control at all locations in both years (Table 2.15). At FCU 2007, control by PRE herbicides ranged from 79% to 99%. With 99% control diclosulam provided best control, followed by the *S*-metolachlor/linuron mixture with 97% control. All three pendimethalin applications rates with 95% to 98% control performed well. Imazethpyr (79%) was the least successful PRE herbicide at FCU. The POST herbicides controlled winter vetch >90%. Best weed control by POST herbicides was provided by chlorimuron with 99%, followed by thifensulfuron (98%) and 2,4-DB (96%). Both cultivation treatments performed equally well in controlling this species; between-within row cultivation with 95% and between row cultivation with 96%. Both black oat cultivars successfully reduced winter vetch infestation in the FCU plots >95%.

At PBU in 2007, winter vetch control by PRE herbicides ranged from 60% to 97%. Best control was provided by diclosulam and the *S*-metolachlor/linuron mixture both with 97% control, followed by the lowest application rate of pendimethalin with 86%. With only 60% control imazethpyr was the least successful, followed by the field application rate of pendimethalin. The POST herbicide treatments controlled winter vetch 53% to 98%. Best control results were achieved by chlorimuron with 98% and thifensulfuron with 89%. The grass active herbicides sethoxydim and fluazifop with 53% and 57% control respectively were the least successful at PBU in 2007. The organic weed control methods provided > 80% control, but the black oat cultivars with 76% to 81% control were less successful than the cultivation treatments with 91% to 94% control.

At FCU in 2008, control by PRE herbicides ranged from 46% to 98%. With 98% control diclosulam performed best of the PRE herbicides, followed by the *S*-metolachlor/linuron mixture with 96%. Imazethapyr (49%) and the lowest application rate of pendimethalin (46%) provided the least control at FCU that year. The POST herbicides controlled winter vetch 51% to 94%. Best control by POST herbicides was achieved by glyphosate with 94% control. The plant oil treatment with 51% and sethoxydim with 54% control were the least successful POST herbicides. Both cultivation treatments provided 94% control of this species. SoilSaver and As_033 controlled winter vetch only to 54% and 55% respectively at FCU in 2008.

Heartwing sorrel. At FCU heartwing sorrel (*Rumex hastatulus* Baldw.) was present at the POST rating in 2007 and 2008, whereas at PBU it was only present at the PRE rating in 2008. Treatment main effect was significant in both years. In FCU 2007 all chemical and organic treatments significantly reduced infestation as compared to the non-treated control (Table 2.16). All PRE treatments, with the exception of linuron (96%) and *S*-metolachlor (92%), controlled this weed species to 99%. The POST herbicides provided 93% to 99% control. Best control was achieved by glyphosate with 99% control, followed by fluazifop and flumioxazin with 98% each. With 93% control 2,4-DB was the least successful POST herbicide. The organic treatments were equally successful at FCU in 2007. Both black oat cultivars controlled heartwing sorrel to 98%. Between-within row cultivation with 99% control performed slightly better than between row cultivation alone (97%).

In 2008 at the same location again all chemical and organic weed control methods, with the exception of the POST herbicide fomesafen, controlled heartwing sorrel significantly better than the non-treated control. The PRE herbicides controlled this species 37% to 99%. Best control was provided by diclosulam and the field application rate of pendimethalin with 99% each, followed by flumioxazin and the highest rate of pendimethalin with 94% each. The least successful PRE herbicide treatments were *S*-metolachlor (37%) and imazethapyr (44%). POST herbicide control ranged from 14% to 93%. Glyphosate was the most successful POST herbicide with 93% mean control, followed by imazethapyr with 80% control. Fomesafen (14%) did not provide significantly better control than the non-treated control and was therefore the least successful POST herbicide treatment. It was followed by 2,4-DB and fluazifop (both 20% control), plant oil (24%) and sethoxydim (27%). At FCU in 2008, both black oat cultivars provided less than 30% control. Between and within row cultivation with 96% control performed slightly better than between row cultivation alone (86%).

At the PRE rating at PBU in 2008, all treatments with the exception of black oat cultivar As_033 controlled heartwing sorrel significantly better than the non-treated control. Weed control by PRE herbicides ranged from 48% to 99%. With 99% control flumioxazin was the best PRE herbicide, followed by diclosulam and metribuzin with 98% each. Pendimethalin, all three rates, controlled heartwing sorrel less successfully than other PREs with mean percent control of 48%, 46% and 79% with increasing rate. The organic treatments controlled this species 20% to 84%. Both black oat cultivars performed poorly; SoilSaver with 29% and As_033 with 20% control only. Between and within row cultivation provided 84% control as compared to 73% by between row cultivation alone.

Corn spurry. Corn spurry (*Spergula arvensis* L.) was present at the POST rating at FCU as well as both ratings at PBU in 2007 and 2008. In both years treatment effect was significant. At FCU in 2007, all chemical and organic weed control methods provided significantly better control than the non-treated control (Table 2.17). PRE herbicides provided 88% to 99% control. Diclosulam and imazethapyr both controlled this species to 88% and were therefore the least successful PRE treatments. Best control was provided when *S*-metolachlor, flumioxazin and all three rates of pendimethalin were applied (99% control each). The POST herbicides controlled corn spurry 22% to 98%. With 98% control flumioxazin achieved the best results of the POSTs in 2007, followed by chlorimuron with 93%. Fomesafen (22%) and 2,4-DB (39%) were the least successful POST herbicides. Both black oat cultivars (SoilSaver 94% and As_033 93%) provided better control than the cultivation treatments (between-within row cultivation 87% and between row cultivation 75%).

In 2008 at FCU, all PRE herbicides provided significantly better control than the non-treated control (Table 2.17). Control by PREs ranged from 42% to 98%. With 98% control the field rate of pendimethalin was the best PRE herbicide, followed by flumioxazin and the *S*-metolachlor/linuron mixture (both 94%). Imazethapyr with 42% control only was the least successful PRE treatment. POST herbicides controlled corn spurry 7% to 94%. Glyphosate provided 94% control and was therefore the best POST herbicide at FCU in 2008. It was followed by flumioxazin. 2,4-DB (6%), sethoxydim (7%) and fluazifop (7%) did not reduce the weed population significantly as compared to the non-treated control. Of the organic treatments, between-within (85%) and between row cultivation (81%) were more successful to control this species than both black oat cultivars. SoilSaver (8%) and As_033 (17%) did not perform significantly better than the non-treated control.

At the PRE rating at PBU in 2007, all PRE herbicide treatments controlled corn spurry significantly better than the non-treated control (Table 2.18). Corn spurry was controlled <90% by PRE herbicides. With 94% mean control the field application rate of pendimethalin was the least successful PRE treatment. Organic weed control varied greatly among treatments. Both cultivation treatments (<10%) controlled corn spurry significantly less than the non-treated control. The black oat cultivars SoilSaver and As_033 controlled corn spurry to 59% and 45% respectively, but this was not significantly better than the non-treated control.

At the POST rating at PBU at 2007 all chemical and organic weed control methods provided significantly better control than the non-treated control. The PRE herbicides provided 86% to 99% control. Metribuzin controlled this species to 86% and was the least successful PRE herbicide. All other PRE herbicides provided weed control of >95%. Weed control by POST herbicides ranged from 37% to 98%. Thifensulfuron and chlorimuron with 98% mean control each were the most successful POST herbicides that year, followed by flumioxazin with 93%. With 37% control fomesafen was the least successful POST herbicide treatment. At the POST rating both black oat cultivars controlled corn spurry to 99%. Between-within (93%) and between row cultivation (88%) provided also good control.

In 2008, all chemical and organic weed control methods, with the exception of both black oat cultivars, significantly reduced the weed infestation at the PRE rating at PBU (Table 2.18). The PRE herbicides controlled this species 76% to 99%. With 99% mean control each flumioxazin, linuron and the *S*-metolachlor/linuron mixture provided best control. *S*-metolachlor applied alone, achieved only 76% control and was therefore the least successful PRE herbicide at that rating. Of the organic weed control methods, only the cultivation treatments provided successful control, but between and within cultivation with 86% provided better control than between row cultivation (55%).

At the POST rating in 2008, all PRE herbicide treatments controlled corn spurry significantly better than the non-treated control. The PRE herbicides achieved 63% to 98% control. With 98% mean control flumioxazin provided the best control of all PRE herbicides, followed by imazethapyr and the *S*-metolachlor/linuron mixture (both 97%). *S*-metolachlor (63%) again provided the least control at PBU that year. The POST herbicides provided 5% to 98%control. Best control was achieved by glyphosate with 98% mean control, followed by the POST applied imazethapyr with 96% control. 2,4-DB (5%), fluazifop (6%) and fomesafen (19%) were the only POST herbicides that did not control significantly better than the non-treated control. The organic treatments with the exception of SoilSaver black oat (7% control) significantly reduced the corn spurry population as compared to the non-treated control. Between and within row cultivation was the better cultivation treatment with 95% control.

Discussion

Chemical weed control

A broad weed spectrum with grass and broadleaf weed species was observed during the two-year experiment. This diverse spectrum makes it difficult to find herbicides to control all weed species equally successful. Annual ryegrass (*Lolium multiflorum* Lam.) and annual bluegrass (*Poa annua* L.) were successfully controlled by the POST applied grass active herbicides sethoxydim and fluazifop. In 2007 ryegrass was controlled more than 95% by these grass active herbicides. In Australia Chambers at al (1995) who investigated annual ryegrass cereal and volunteer cereal control by selective post-herbicides found similar results. In their study annual ryegrass was controlled more than 98% by sethoxydim as well as fluazifop. In a study in Australia conducted already in 1979, other herbicides (diclofop) were found to control annual ryegrass successfully in direct-drilled lupin (*Lupinus angustifolius* L.) (Fua, 1981). Annual bluegrass was controlled to more than 65% by sethoxydim and fluazifop. We discovered that this grass was better controlled by the PRE applied herbicides. One of these PRE herbicides was *S*-metolachlor (which is one of the three active ingredients currently registered for the use in lupin in the USA), a chloroacetamide, which controlled annual bluegrass to more than 90% in 2008. Mitich et al. (1987) evaluated the same herbicide in their 1985 study to find PRE herbicides to control winter annual weeds in lupin and found that *S*-metolachlor gave 90% to 98% control of annual bluegrass. In the same study *S*-metolachlor controlled shepherd's purse (*Capsella bursa-pastoris* L.) and wild radish (*Raphanus raphanistrum* L.) to more than 90% (Mitich et al., 1987). Our experiment showed variable mean control of shepherd's purse by this herbicide, with more than 95% control in 2007 and less than

50% in 2008. But *S*-metolachlor gave good wild radish control (>80%) in our experiment in 2007. We also found that wild radish was successfully controlled to more than 90% in our study by metibuzin, a triazine. Similar results were observed by Code and Reeves (1981) who evaluated herbicides that control wild radish successfully in grain lupin production in Australia. It was found that metibuzin gave more than 95% wild radish control.

In our two year field experiment the three rates of pendimethalin (0.5x, 1x, 2x) overall provided good weed control. Shepherd's purse was controlled to more than 90% in 2007. Mean control increased with increasing rate. Mitich et al. (1989) used the same application rates in their experiment and found the same trend; control of shepherd's purse improved from 70% to 100% with increasing rate. Other weed species successfully controlled by pendimethalin in our experiment were corn spurry (*Spergula avensis* L.), black medic (*Medicago lupulina* L.), winter vetch (*Vicia villosa* Roth), henbit (*Lamium amplexicaule* L.), Carolina geranium (*Geranium carolinianum* L.) and yellow nutsedge (*Cyperus esculentus* L.).

Ivany and McCully (1994) showed that imazethapyr applied PRE and POST in lupin provided good broadleaf weed control (80 to 91%). Similarly, we also found that imazethapyr controlled almost all broadleaf weed species to more than 80% when applied PRE or POST, with the exception of black medic and crimson clover (less than 70%).

In 2007 we used chlorimuron and thifensulfuron, both sulfonyl urea herbicides that are POST applied. Almost all weed species encountered in our experiment were controlled to more than 90% in 2007. Nonetheless because of total crop loss due to these two herbicides in 2007, alternative compounds were substituted in 2008.

Glyphosate, which is registered as a POST directed spray for the use in lupins in the USA, provided successful weed control (> 80% in general) of almost all weed species encountered. This is not surprising since glyphosate is a non-selective herbicide.

Carfentrazone, which is also a registered as a POST directed treatment for lupin in the USA, did not provide uniformly good weed control. It is a selective broadleaf herbicide. Carfentrazone was only applied in 2008. It controlled black medic and shepherd's purse successfully to about 70%. Control of other weed species was less than 70% in this experiment.

Even though *S*-metolachlor/linuron mixture is not registered for use in white lupin in the Southeastern USA it has been used over a decade as the standard weed control program by Noffsinger et al. (1998, 2000). It has been included in this study as an additional control. It was one of the best chemical weed control options, since it controlled almost all of the species encountered to more than 80%. The only exceptions were cutleaf-evening primrose and yellow nutsedge which at certain locations were controlled to 72% and 73% respectively.

Organic weed control

As legumes, lupins play an important role in organic farming for the fixation of nitrogen. The use of synthetic herbicides is prohibited in organic farming, so non-chemical weed control methods need to be investigated. Our field experiment showed that between and within row cultivation by hoeing successfully reduced most weed species present to more than 80%, including shepherd's purse, annual bluegrass, crimson clover, black medic, winter vetch, cutleaf-evening primrose (*Oenothera laciniata* Hill) and heartwing sorrel (*Rumex hastatulus* Baldw.). George (2005) mentioned that harrowing in lupin plants up to a 10 cm height aids in the control of weed pressure, but he also said that taller crop plants will likely be injured using this method. Hand-hoeing is more selective than harrowing and may not injure the crop, but it is labor intense and therefore expensive. It can be a good option for organic farming since it is usually done on a smaller scale and the value of organic products is generally higher.

The two black oat cultivars used in our experiment provided very good control of annual ryegrass, shepherd's purse, Carolina geranium and yellow nutsedge (>90%), but were not successful in the control of other weed species especially corn spurry (*Spergula arvensis* L.). Black oat is commonly used as pasture, green manure, cover crop and for erosion control (CTAHR, 11-07-2008). *A.strigosa* Schreb. used to be a minor cereal of poor soils, but is now commonly grown as winter forage, cover crop and for grain production in South America, especially in Brazil (Anthony, 2007). In lupin seed production it is not used as a cover crop but as a companion crop. Due to seed size differences it can be harvested/combined with the main crop or it may be terminated by a selective grass herbicide (fops and dims) once its purpose is fulfilled. According to Bowman et al. (1998) black oat, especially SoilSaver, outcompete weeds by shading due to a large biomass production. Black oat produces allelopathic compounds which inhibit weed growth (Bowman et al., 1998). This study was not designed to assess successful weed control by black oat cultivars due to allelopathy or shading or maybe a combination of both. Since lupins develop a full canopy slowly they cannot shade the weeds during their early establishment. By using black oat cultivars as a companion for lupin this problem was solved.

The results of our experiment show that good weed control can be achieved by using a broad spectrum of herbicides that are currently not registered for use in lupin production in the US as well as organic treatments. Some of these promising herbicides are imazethapyr, fluazifop, sethoxydim, diclosulam and metribuzin. Nonetheless additional research will be necessary to evaluate the effect of these herbicides on injury and the yield potential of lupin (see Chapter III). With glyphosate and *S*-metolachlor, which are registered for use in lupin in the US, good weed control in lupin is possible, but this list only allows for narrow active ingredient rotation, which is aiding in potential resistance development in weed species. Therefore it is necessary to expand the list of weed control methods in US lupin production.

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Table 2.01: Herbicide program used to evaluate weed control in white lupin (*L. albus* L.) in 2007 and 2008 at Field Crops Unit (Shorter) and Plant Breeding Unit (Tallassee) of the Alabama Agricultural Experiment Station. Because of total crop loss due to treatments 12 and 16 in 2007, alternative compounds were substituted in 2008.

Treatment			Rate		
No	Trade Name	Active Ingredient	Rate	Unit	Treatment class
1	Nontreated	—	—	—	—
2	Dual and	S-metolachlor	1.12	kg ai/ha	PRE
	Lorox	Linuron	1.12	kg ai/ha	PRE
3	Sencor	Metribuzin	0.42	kg ai/ha	PRE
4	Lorox	Linuron	1.12	kg ai/ha	PRE
5	Dual	S-metolachlor	1.12	kg ai/ha	PRE
6	Prowl H2O	Pendimethalin (0.5x)	0.84	kg ai/ha	PRE
7	Prowl H2O	Pendimethalin (1x)	1.68	kg ai/ha	PRE
8	Prowl H2O	Pendimethalin (2x)	3.36	kg ai/ha	PRE
9	Strongarm	Diclosulam	0.03	kg ai/ha	PRE
10	Valor	Flumioxazin	0.07	kg ai/ha	PRE
11	Pursuit	Imazethapyr	0.07	kg ai/ha	PRE
12	Hamony (2007)	Thifensulfuron	0.07	kg ai/ha	POST
	Aim (2008)	Carfentrazone	0.03	kg ai/ha	PDS
13	Fusilade	Fluazifop	0.84	kg ai/ha	POST
14	Reflex	Fomesafen	0.28	kg ai/ha	POST
15	2,4-DB	2,4-DB	0.28	kg ai/ha	POST
16	Classic (2007)	Chlorimuron	0.05	kg ai/ha	POST
	Weedzap (2008)	Plant oil	190	mL/gal	PDS
17	Honcho Plus	Glyphosate	1.12	kg ai/ha	PDS
18	Poast Plus	Sethoxydim	0.28	kg ai/ha	POST
19	Valor	Flumioxazin	0.07	kg ai/ha	PDS
20	Pursuit	Imazethapyr	0.07	kg ai/ha	POST
21	between row cultivation				Organic
22	between and within-row				Organic
23	SoilSaver Black Oat				Organic
24	As_033 BO				Organic

Table 2.02: Weed species frequency in percent of all observed in plots with *L. albus* cultivars AU Alpha, AU Homer and ABL 1082 at Field Crops Unit (Shorter) and Plant Breeding Unit (Tallassee) of the Alabama Agricultural Experiment Station 6 weeks after PRE application in 2007 and 2008.

Weed species			Rated 6 wks after PRE in 2007						Rated 6 wks after PRE in 2008					
			FCU			PBU			FCU			PBU		
Code	Bayer Code	Latin binomial	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082
GECA5	GERCA	*Geranium carolinianum* L.	-	-	-	-	-	-	-	-	-	-	-	-
TRIN3	TRFIN	*Trifolium incarnatum* L.	-	-	-	-	-	-	-	-	-	-	-	-
CABU2	CARBR	*Capsella bursa-pastoris* (L.) Medik.	-	-	-	-	-	-	-	-	-	-	-	-
RARA2	RAPRA	*Raphanus raphanistrum* L.	-	-	-	-	-	-	-	-	-	-	-	-
LOMU	LOLMU	*Lolium multiflorum* Lam.	-	-	-	-	-	-	-	-	-	-	-	-
CYES	CYPES	*Cyperus esculentus* L.	-	-	-	-	-	-	-	-	-	-	-	-
OELA	OEOLA	*Oenothera laciniata* Hill	-	-	-	-	-	-	-	-	-	-	-	-
VIVI	VICVI	*Vicia villosa* Roth	-	-	-	-	-	-	-	-	-	-	-	-
MELU	MEDLU	*Medicago lupulina* L.	-	-	-	-	-	-	-	-	-	-	-	-
CODI6	COPDI	*Coronopus didymus* (L.) Sm.	-	-	-	-	-	-	-	-	-	100	100	100
POAN	POANN	*Poa annua* L.	-	-	-	-	-	-	-	-	-	100	100	100
RUHA2	RUMHA	*Rumex hastatulus* Baldw.	-	-	-	-	-	-	-	-	-	100	100	100
LAAM	LAMAM	*Lamium amplexicaule* L.	-	-	-	100	100	100	-	-	-	100	100	100
SPAR	SPRAR	*Spergula arvensis* L.	-	-	-	100	100	75	-	-	-	50	75	50

Table 2.03: Weed species frequency in percent of all observed in plots with *L. albus* cultivars AU Alpha, AU Homer and ABL 1082 at Field Crops Unit (Shorter) and Plant Breeding Unit (Tallassee) of the Alabama Agricultural Experiment Station 9 and 5 weeks after POST application in 2007 and 2008, respectively.

	Weed species		Rated 9 wk after POST treatment in 2007						Rated 5 wk after POST treatment in 2008					
			FCU			PBU			FCU			PBU		
Code	Bayer Code	Latin binomial	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082	AU Alpha	AU Homer	ABL 1082
LAAM	LAMAM	*Lamium amplexicaule* L.	-	-	-	-	-	-	-	-	-	-	-	-
CODI6	COPDI	*Coronopus didymus* (L.) Sm.	-	-	-	-	-	-	-	-	-	100	100	100
POAN	POANN	*Poa annua* L.	-	-	-	-	-	-	-	-	-	100	100	100
MELU	MEDLU	*Medicago lupulina* L.	-	-	-	-	-	-	50	75	83	-	-	-
GECA5	GERCA	*Geranium carolinianum* L.	-	-	-	100	100	100	-	-	-	-	-	-
CYES	CYPES	*Cyperus esculentus* L.	-	-	-	100	100	100	-	-	-	-	-	-
TRIN3	TRFIN	*Trifolium incarnatum* L.	100	100	75	100	100	100	-	-	-	-	-	-
RARA2	RAPRA	*Raphanus raphanistrum* L.	100	100	75	100	100	100	-	-	-	-	-	-
LOMU	LOLMU	*Lolium multiflorum* Lam.	100	100	100	75	50	100	-	-	-	-	-	-
VIVI	VICVI	*Vicia villosa* Roth	75	75	100	100	100	100	75	100	100	-	-	-
RUHA2	RUMHA	*Rumex hastatulus* Baldw.	100	100	100	-	-	-	100	100	100	-	-	-
CABU2	CAPBP	*Capsella bursa-pastoris* (L.) Medik.	100	100	100	100	100	100	-	-	-	50	100	-
OELA	OEOLA	*Oenothera laciniata* Hill	100	100	100	100	100	100	75	100	100	100	100	100
SPAR	SPRAR	*Spergula arvensis* L.	100	100	100	100	100	75	100	100	100	50	75	50

Table 2.04: Black medic (*Medicago lupulina* L.) control as influenced by herbicide and organic treatments at POST rating at Field Crops Unit in Shorter, AL in 2008.

Treatment			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*
			%		
1	None	Control	0	(0 , 14)	
2	S-metolachlor/Linuron	PRE	98	(82 , 98)	<0.0001
3	Metribuzin	PRE	78	(51 , 96)	<0.0001
4	Linuron	PRE	94	(73 , 100)	<0.0001
5	S-metolachlor	PRE	86	(62 , 99)	<0.0001
6	Pendimethalin (0.5x)	PRE	66	(37 , 89)	0.0001
7	Pendimethalin (1x)	PRE	92	(71 , 100)	<0.0001
8	Pendimethalin (2x)	PRE	96	(78 , 99)	<0.0001
9	Diclosulam	PRE	97	(79 , 99)	<0.0001
10	Flumioxazin	PRE	99	(86 , 97)	<0.0001
11	Imazethapyr	PRE	27	(6 , 55)	0.0723
12	Carfentrazone	POST	73	(44 , 94)	<0.0001
13	Fluazifop	POST	61	(32 , 87)	0.0002
14	Fomesafen	POST	54	(25 , 81)	0.0009
15	2,4-DB	POST	86	(61 , 99)	<0.0001
16	Plant oil	POST	46	(19 , 74)	0.0039
17	Glyphosate	POST	98	(83 , 98)	<0.0001
18	Sethoxydim	POST	38	(13 , 67)	0.0145
19	Flumioxazin	POST	83	(57 , 99)	<0.0001
20	Imazethapyr	POST	45	(18 , 74)	0.0044
21	Between row cultivation	Organic	82	(55 , 98)	<0.0001
22	Between-within row	Organic	92	(69 , 100)	<0.0001
23	SoilSaver Black Oat	Organic	42	(16 , 71)	0.0078
24	As_033 Black Oat	Organic	54	(25 , 81)	0.0009

Table 2.05: Lesser swinecress [*Coronopus didymus* (L.) Sm.] control as influenced by herbicide and organic treatment by rating at Plant Breeding Unit in Tallassee, AL in 2008.

Treatment			PRE			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
					%			
1	None	Control	3	(1 , 7)		0	(0 , 6)	
2	S-metolachlor/Linuron	PRE	93	(80 , 99)	<0.0001	94	(80 ,100)	<0.0001
3	Metribuzin	PRE	96	(86 ,100)	<0.0001	87	(70 , 98)	<0.0001
4	Linuron	PRE	94	(81 ,100)	<0.0001	93	(79 ,100)	<0.0001
5	S-metolachlor	PRE	86	(71 , 97)	<0.0001	75	(55 , 91)	<0.0001
6	Pendimethalin (0.5x)	PRE	45	(26 , 65)	<0.0001	39	(20 , 61)	0.0004
7	Pendimethalin (1x)	PRE	41	(23 , 60)	<0.0001	46	(25 , 67)	0.0001
8	Pendimethalin (2x)	PRE	78	(60 , 92)	<0.0001	71	(49 , 88)	<0.0001
9	Diclosulam	PRE	98	(90 ,100)	<0.0001	94	(80 ,100)	<0.0001
10	Flumioxazin	PRE	99	(91 , 99)	<0.0001	95	(82 ,100)	<0.0001
11	Imazethapyr	PRE	95	(83 ,100)	<0.0001	91	(75 , 99)	<0.0001
12	Carfentrazone	POST	N/A			14	(3 , 32)	0.1671
13	Fluazifop	POST	N/A			5	(0 , 19)	0.7847
14	Fomesafen	POST	N/A			42	(22 , 64)	0.0002
15	2,4-DB	POST	N/A			68	(46 , 86)	<0.0001
16	Plant oil	POST	N/A			7	(0 , 21)	0.6714
17	Glyphosate	POST	N/A			92	(76 , 99)	<0.0001
18	Sethoxydim	POST	N/A			27	(11 , 48)	0.0081
19	Flumioxazin	POST	N/A			10	(1 , 27)	0.3597
20	Imazethapyr	POST	N/A			85	(67 , 97)	<0.0001
21	Between row cultivation	Organic	73	(54 , 88)	<0.0001	76	(56 , 92)	<0.0001
22	Between-within row	Organic	84	(68 , 96)	<0.0001	95	(81 ,100)	<0.0001
23	SoilSaver Black Oat	Organic	17	(5 , 34)	0.2111	47	(26 , 68)	<0.0001
24	As_033 Black Oat	Organic	18	(6 , 36)	0.1432	27	(11 , 48)	0.0081

Table 2.06: Annual bluegrass (*Poa annua* L.) control as influenced by herbicide and organic treatment by rating at Plant Breeding Unit in Tallassee, AL in 2008.

Treatment			PRE			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
				%				
1	None	Control	4	(2 , 8)		0	(0 , 4)	
2	S-metolachlor/Linuron	PRE	94	(82 ,100)	<0.0001	92	(81 , 99)	<0.0001
3	Metribuzin	PRE	96	(85 ,100)	<0.0001	77	(62 , 89)	<0.0001
4	Linuron	PRE	98	(89 ,100)	<0.0001	78	(63 , 90)	<0.0001
5	S-metolachlor	PRE	95	(83 ,100)	<0.0001	93	(83 , 99)	<0.0001
6	Pendimethalin (0.5x)	PRE	86	(69 , 97)	<0.0001	76	(60 , 88)	<0.0001
7	Pendimethalin (1x)	PRE	89	(74 , 98)	<0.0001	82	(68 , 93)	<0.0001
8	Pendimethalin (2x)	PRE	93	(79 ,100)	<0.0001	75	(59 , 88)	<0.0001
9	Diclosulam	PRE	97	(86 ,100)	<0.0001	13	(4 , 25)	0.0616
10	Flumioxazin	PRE	97	(87 ,100)	<0.0001	81	(66 , 92)	0.0000
11	Imazethapyr	PRE	90	(75 , 99)	<0.0001	4	(0 , 13)	0.6698
12	Carfentrazone	POST	N/A			34	(19 , 50)	<0.0001
13	Fluazifop	POST	N/A			66	(50 , 81)	<0.0001
14	Fomesafen	POST	N/A			40	(24 , 56)	<0.0001
15	2,4-DB	POST	N/A			50	(34 , 66)	<0.0001
16	Plant oil	POST	N/A			61	(45 , 77)	<0.0001
17	Glyphosate	POST	N/A			81	(67 , 92)	<0.0001
18	Sethoxydim	POST	N/A			66	(50 , 81)	<0.0001
19	Flumioxazin	POST	N/A			58	(41 , 73)	<0.0001
20	Imazethapyr	POST	N/A			0	(3 , 3)	1.0000
21	Between row cultivation	Organic	68	(48 , 85)	<0.0001	61	(45 , 76)	<0.0001
22	Between-within row	Organic	74	(55 , 89)	<0.0001	87	(74 , 96)	<0.0001
23	SoilSaver Black Oat	Organic	56	(36 , 75)	<0.0001	88	(75 , 96)	<0.0001
24	As_033 Black Oat	Organic	32	(15 , 52)	0.0031	87	(74 , 96)	<0.0001

Table 2.07: Carolina geranium (*Geranium carolinianum* L.) control as influenced by herbicide and organic treatment at POST rating at Plant Breeding Unit in Tallassee, AL in 2007.

Treatment			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*
			%		
1	None	Control	0	(0 , 2)	
2	S-metolachlor/Linuron	PRE	99	(94 ,100)	<0.0001
3	Metribuzin	PRE	98	(91 ,100)	<0.0001
4	Linuron	PRE	94	(85 , 99)	<0.0001
5	S-metolachlor	PRE	96	(88 ,100)	<0.0001
6	Pendimethalin (0.5x)	PRE	93	(84 , 99)	<0.0001
7	Pendimethalin (1x)	PRE	89	(78 , 97)	<0.0001
8	Pendimethalin (2x)	PRE	94	(85 , 99)	<0.0001
9	Diclosulam	PRE	93	(83 , 98)	<0.0001
10	Flumioxazin	PRE	96	(89 ,100)	<0.0001
11	Imazethapyr	PRE	95	(86 , 99)	<0.0001
12	Thifensulfuron	POST	97	(91 ,100)	<0.0001
13	Fluazifop	POST	94	(85 , 99)	<0.0001
14	Fomesafen	POST	83	(70 , 92)	<0.0001
15	2,4-DB	POST	94	(85 , 99)	<0.0001
16	Chlorimuron	POST	67	(52 , 80)	<0.0001
17	Glyphosate	POST	86	(74 , 94)	<0.0001
18	Sethoxydim	POST	84	(71 , 93)	<0.0001
19	Flumioxazin	POST	80	(67 , 91)	<0.0001
20	Imazethapyr	POST	91	(81 , 98)	<0.0001
21	Between row cultivation	Organic	93	(84 , 99)	<0.0001
22	Between-within row	Organic	97	(90 ,100)	<0.0001
23	SoilSaver Black Oat	Organic	98	(92 ,100)	<0.0001
24	As_033 Black Oat	Organic	98	(92 ,100)	<0.0001

Table 2.08: Yellow nutsedge (*Cyperus esculentus* L.) control as influenced by herbicide and organic treatment at POST rating at Plant Breeding Unit in Tallassee, AL in 2007.

Treatment			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*
				%	
1	None	Control	0	(0 , 3)	
2	S-metolachlor/Linuron	PRE	73	(60 , 84)	<0.0001
3	Metribuzin	PRE	76	(63 , 87)	<0.0001
4	Linuron	PRE	84	(72 , 93)	<0.0001
5	S-metolachlor	PRE	97	(90 ,100)	<0.0001
6	Pendimethalin (0.5x)	PRE	97	(91 ,100)	<0.0001
7	Pendimethalin (1x)	PRE	95	(87 , 99)	<0.0001
8	Pendimethalin (2x)	PRE	90	(80 , 97)	<0.0001
9	Diclosulam	PRE	67	(53 , 80)	<0.0001
10	Flumioxazin	PRE	91	(81 , 97)	<0.0001
11	Imazethapyr	PRE	86	(75 , 94)	<0.0001
12	Thifensulfuron	POST	82	(70 , 91)	<0.0001
13	Fluazifop	POST	94	(86 , 99)	<0.0001
14	Fomesafen	POST	91	(81 , 97)	<0.0001
15	2,4-DB	POST	93	(84 , 99)	<0.0001
16	Chlorimuron	POST	80	(67 , 90)	<0.0001
17	Glyphosate	POST	85	(73 , 93)	<0.0001
18	Sethoxydim	POST	97	(91 ,100)	<0.0001
19	Flumioxazin	POST	89	(78 , 96)	<0.0001
20	Imazethapyr	POST	91	(81 , 97)	<0.0001
21	Between row cultivation	Organic	78	(65 , 88)	<0.0001
22	Between-within row	Organic	86	(75 , 94)	<0.0001
23	SoilSaver Black Oat	Organic	99	(94 ,100)	<0.0001
24	As_033 Black Oat	Organic	99	(94 ,100)	<0.0001

Table 2.09: Henbit (*Lamium amplexicaule* L.) control as influenced by herbicide and organic treatment at PRE rating at Plant Breeding Unit in Tallassee, AL in 2007 and 2008.

Treatment			2007			2008		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%					
1	None	Control	22	(17 , 28)		1	(0 , 3)	
2	S-metolachlor/Linuron	PRE	99	(92 , 99)	<0.0001	92	(82 , 98)	<0.0001
3	Metribuzin	PRE	97	(88 ,100)	<0.0001	97	(90 ,100)	<0.0001
4	Linuron	PRE	95	(84 ,100)	<0.0001	86	(74 , 95)	<0.0001
5	S-metolachlor	PRE	90	(77 , 98)	<0.0001	98	(91 ,100)	<0.0001
6	Pendimethalin (0.5x)	PRE	97	(87 ,100)	<0.0001	88	(77 , 96)	<0.0001
7	Pendimethalin (1x)	PRE	99	(91 , 99)	<0.0001	97	(90 ,100)	<0.0001
8	Pendimethalin (2x)	PRE	99	(92 , 99)	<0.0001	98	(92 ,100)	<0.0001
9	Diclosulam	PRE	99	(91 , 99)	<0.0001	98	(91 ,100)	<0.0001
10	Flumioxazin	PRE	98	(90 ,100)	<0.0001	99	(93 ,100)	<0.0001
11	Imazethapyr	PRE	93	(81 , 99)	<0.0001	99	(93 ,100)	<0.0001
12	Thifensulfuron (2007)	POST	N/A			N/A		
12	Carfentrazone (2008)	POST	N/A			N/A		
13	Fluazifop	POST	N/A			N/A		
14	Fomesafen	POST	N/A			N/A		
15	2,4-DB	POST	N/A			N/A		
16	Chlorimuron (2007)	POST	N/A			N/A		
16	Plant oil (2008)	POST	N/A			N/A		
17	Glyphosate	POST	N/A			N/A		
18	Sethoxydim	POST	N/A			N/A		
19	Flumioxazin	POST	N/A			N/A		
20	Imazethapyr	POST	N/A			N/A		
21	Between row cultivation	Organic	5	(0 , 15)	0.0671	49	(34 , 64)	<0.0001
22	Between-within row	Organic	5	(0 , 16)	0.0960	73	(58 , 85)	<0.0001
23	SoilSaver Black Oat	Organic	49	(31 , 67)	0.0528	7	(1 , 17)	0.5615
24	As_033 Black Oat	Organic	26	(12 , 44)	1.0000	3	(0 , 11)	0.9972

Table 2.10: Crimson clover (*Trifolium incarnatum* L.) control as influenced by herbicide and organic treatments at the POST rating at Field Crops Unit in Shorter, AL and Plant Breeding Unit in Tallassee, AL in 2007.

Treatment			FCU			PBU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%					
1	None	Control	0	(0 , 7)		0	(0 , 0)	
2	S-metolachlor/Linuron	PRE	99	(92 , 99)	<0.0001	99	(99 , 99)	<0.0001
3	Metribuzin	PRE	99	(92 , 99)	<0.0001	99	(98 , 99)	<0.0001
4	Linuron	PRE	98	(91 ,100)	<0.0001	99	(99 , 99)	<0.0001
5	S-metolachlor	PRE	89	(75 , 98)	<0.0001	99	(99 , 99)	<0.0001
6	Pendimethalin (0.5x)	PRE	93	(80 , 99)	<0.0001	99	(99 , 99)	<0.0001
7	Pendimethalin (1x)	PRE	78	(62 , 91)	<0.0001	99	(99 , 99)	<0.0001
8	Pendimethalin (2x)	PRE	97	(88 ,100)	<0.0001	99	(99 , 99)	<0.0001
9	Diclosulam	PRE	98	(91 ,100)	<0.0001	99	(99 , 99)	<0.0001
10	Flumioxazin	PRE	98	(90 ,100)	<0.0001	99	(99 , 99)	<0.0001
11	Imazethapyr	PRE	47	(29 , 65)	<0.0001	99	(99 , 99)	<0.0001
12	Carfentrazone	POST	87	(73 , 97)	<0.0001	99	(99 , 99)	<0.0001
13	Fluazifop	POST	74	(57 , 88)	<0.0001	98	(98 , 99)	<0.0001
14	Fomesafen	POST	61	(43 , 78)	<0.0001	99	(98 , 99)	<0.0001
15	2,4-DB	POST	48	(31 , 66)	<0.0001	98	(97 , 98)	<0.0001
16	Plant oil	POST	98	(89 ,100)	<0.0001	99	(99 , 99)	<0.0001
17	Glyphosate	POST	92	(80 , 99)	<0.0001	99	(99 , 99)	<0.0001
18	Sethoxydim	POST	50	(32 , 68)	<0.0001	99	(99 , 99)	<0.0001
19	Flumioxazin	POST	89	(75 , 98)	<0.0001	99	(98 , 99)	<0.0001
20	Imazethapyr	POST	64	(46 , 80)	<0.0001	99	(98 , 99)	<0.0001
21	Between row cultivation	Organic	91	(77 , 98)	<0.0001	99	(98 , 99)	<0.0001
22	Between-within row	Organic	92	(79 , 99)	<0.0001	99	(99 , 99)	<0.0001
23	SoilSaver Black Oat	Organic	73	(56 , 88)	<0.0001	99	(99 , 99)	<0.0001
24	As_033 Black Oat	Organic	85	(70 , 96)	<0.0001	98	(98 , 99)	<0.0001

Table 2.11: Wild radish (*Raphanus raphanistrum* L.) control as influenced by herbicide and organic treatment at POST rating at Field Crops Unit in Shorter, AL and Plant breeding Unit in Tallassee, AL in 2008.

Treatment			FCU			PBU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%					
1	None	Control	2	(0 , 13)		0	(0 , 2)	
2	S-metolachlor/Linuron	PRE	98	(90 ,100)	<0.0001	99	(96 ,100)	<0.0001
3	Metribuzin	PRE	91	(77 , 99)	<0.0001	98	(94 ,100)	<0.0001
4	Linuron	PRE	93	(81 ,100)	<0.0001	99	(96 ,100)	<0.0001
5	S-metolachlor	PRE	80	(63 , 93)	<0.0001	94	(88 , 98)	<0.0001
6	Pendimethalin (0.5x)	PRE	63	(43 , 80)	<0.0001	97	(91 , 99)	<0.0001
7	Pendimethalin (1x)	PRE	93	(79 , 99)	<0.0001	96	(91 , 99)	<0.0001
8	Pendimethalin (2x)	PRE	96	(86 ,100)	<0.0001	99	(96 ,100)	<0.0001
9	Diclosulam	PRE	98	(89 ,100)	<0.0001	99	(96 ,100)	<0.0001
10	Flumioxazin	PRE	96	(85 ,100)	<0.0001	98	(94 ,100)	<0.0001
11	Imazethapyr	PRE	95	(83 ,100)	<0.0001	99	(96 ,100)	<0.0001
12	Carfentrazone	POST	74	(55 , 89)	<0.0001	96	(90 , 99)	<0.0001
13	Fluazifop	POST	43	(25 , 62)	0.0008	90	(82 , 95)	<0.0001
14	Fomesafen	POST	99	(91 , 99)	<0.0001	99	(96 ,100)	<0.0001
15	2,4-DB	POST	63	(44 , 80)	<0.0001	98	(93 ,100)	<0.0001
16	Plant oil	POST	99	(92 , 99)	<0.0001	99	(96 ,100)	<0.0001
17	Glyphosate	POST	57	(38 , 76)	<0.0001	97	(92 ,100)	<0.0001
18	Sethoxydim	POST	83	(66 , 95)	<0.0001	95	(90 , 99)	<0.0001
19	Flumioxazin	POST	72	(53 , 87)	<0.0001	97	(92 ,100)	<0.0001
20	Imazethapyr	POST	71	(53 , 87)	<0.0001	99	(95 ,100)	<0.0001
21	Between row cultivation	Organic	92	(78 , 99)	<0.0001	95	(89 , 99)	<0.0001
22	Between-within row	Organic	97	(87 ,100)	<0.0001	99	(95 ,100)	<0.0001
23	SoilSaver Black Oat	Organic	77	(59 , 91)	<0.0001	95	(90 , 99)	<0.0001
24	As_033 Black Oat	Organic	69	(51 , 85)	<0.0001	96	(90 , 99)	<0.0001

Table 2.12: Shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.] control as influenced by herbicide and organic treatments at POST rating at Field Crops Unit in Shorter, AL in 2007 and at Plant Breeding Unit in Tallassee, AL in 2007 and 2008.

			2007						2008		
Treatment			FCU			PBU			PBU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%								
1	None	Control	3	(0 , 7)		0	(0 , 2)		0	(0 , 15)	
2	S-metolachlor/Linuron	PRE	98	(95 ,100)	<0.0001	99	(96 ,100)	<0.0001	92	(70 ,100)	<0.0001
3	Metribuzin	PRE	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	93	(72 ,100)	<0.0001
4	Linuron	PRE	98	(95 ,100)	<0.0001	99	(96 ,100)	<0.0001	98	(81 , 98)	<0.0001
5	S-metolachlor	PRE	97	(94 ,100)	<0.0001	95	(90 , 99)	<0.0001	42	(15 , 71)	0.0651
6	Pendimethalin (0.5x)	PRE	97	(93 , 99)	<0.0001	90	(82 , 95)	<0.0001	3	(2 , 20)	0.9999
7	Pendimethalin (1x)	PRE	99	(96 ,100)	<0.0001	96	(91 , 99)	<0.0001	21	(3 , 49)	0.3890
8	Pendimethalin (2x)	PRE	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	64	(35 , 89)	0.0051
9	Diclosulam	PRE	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	99	(85 , 96)	<0.0001
10	Flumioxazin	PRE	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	98	(81 , 98)	<0.0001
11	Imazethapyr	PRE	89	(82 , 94)	<0.0001	97	(92 ,100)	<0.0001	85	(59 , 99)	0.0002
12	Thifensulfuron	POST	98	(95 ,100)	<0.0001	99	(95 ,100)	<0.0001	N/A		
12	Carfentrazone	POST	N/A			N/A			69	(39 , 91)	0.0028
13	Fluazifop	POST	98	(95 ,100)	<0.0001	95	(89 , 99)	<0.0001	32	(9 , 61)	0.1578
14	Fomesafen	POST	97	(92 , 99)	<0.0001	98	(94 ,100)	<0.0001	94	(73 ,100)	<0.0001
15	2,4-DB	POST	99	(96 ,100)	<0.0001	90	(83 , 95)	<0.0001	21	(3 , 49)	0.3932
16	Chlorimuron	POST	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	N/A		
16	Plant oil	POST	N/A			N/A			29	(7 , 58)	0.2074
17	Glyphosate	POST	97	(93 , 99)	<0.0001	99	(95 ,100)	<0.0001	96	(76 , 99)	<0.0001
18	Sethoxydim	POST	97	(93 , 99)	<0.0001	91	(84 , 96)	<0.0001	36	(12 , 66)	0.1083
19	Flumioxazin	POST	98	(94 ,100)	<0.0001	91	(83 , 96)	<0.0001	60	(31 , 86)	0.0082
20	Imazethapyr	POST	98	(94 ,100)	<0.0001	96	(91 , 99)	<0.0001	97	(79 , 99)	<0.0001
21	Between row cultivation	Organic	97	(93 , 99)	<0.0001	99	(96 ,100)	<0.0001	93	(72 ,100)	<0.0001
22	Between-within row	Organic	98	(94 ,100)	<0.0001	98	(94 ,100)	<0.0001	98	(83 , 97)	<0.0001
23	SoilSaver Black Oat	Organic	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	68	(38 , 91)	0.0032
24	As_033 Black Oat	Organic	99	(96 ,100)	<0.0001	99	(96 ,100)	<0.0001	83	(56 , 98)	0.0003

Table 2.13: Annual ryegrass (*Lolium multiflorum* Lam.) control as influenced by herbicide and organic treatment at POST rating at Field Crops Unit in Shorter, AL and Plant Breeding Unit in Tallassee, AL in 2007.

Treatment			FCU			PBU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%					
1	None	Control	0	(0 , 1)		0	(0 , 2)	
2	S-metolachlor/Linuron	PRE	98	(96 ,100)	<0.0001	97	(90 ,100)	<0.0001
3	Metribuzin	PRE	98	(96 , 99)	<0.0001	78	(66 , 88)	<0.0001
4	Linuron	PRE	96	(94 , 98)	<0.0001	90	(81 , 97)	<0.0001
5	S-metolachlor	PRE	98	(95 , 99)	<0.0001	93	(85 , 98)	<0.0001
6	Pendimethalin (0.5x)	PRE	98	(96 ,100)	<0.0001	58	(44 , 70)	<0.0001
7	Pendimethalin (1x)	PRE	98	(96 , 99)	<0.0001	92	(83 , 98)	<0.0001
8	Pendimethalin (2x)	PRE	99	(97 ,100)	<0.0001	82	(70 , 91)	<0.0001
9	Diclosulam	PRE	95	(92 , 98)	<0.0001	68	(55 , 79)	<0.0001
10	Flumioxazin	PRE	98	(96 , 99)	<0.0001	80	(69 , 90)	<0.0001
11	Imazethapyr	PRE	95	(92 , 98)	<0.0001	87	(77 , 95)	<0.0001
12	Thifensulfuron	POST	97	(95 , 99)	<0.0001	64	(51 , 76)	<0.0001
13	Fluazifop	POST	98	(96 , 99)	<0.0001	99	(95 ,100)	<0.0001
14	Fomesafen	POST	97	(95 , 99)	<0.0001	67	(54 , 79)	<0.0001
15	2,4-DB	POST	94	(91 , 97)	<0.0001	76	(64 , 87)	<0.0001
16	Chlorimuron	POST	93	(90 , 96)	<0.0001	65	(52 , 77)	<0.0001
17	Glyphosate	POST	99	(97 ,100)	<0.0001	89	(79 , 96)	<0.0001
18	Sethoxydim	POST	98	(96 ,100)	<0.0001	96	(89 ,100)	<0.0001
19	Flumioxazin	POST	97	(94 , 99)	<0.0001	80	(68 , 89)	<0.0001
20	Imazethapyr	POST	95	(92 , 97)	<0.0001	77	(65 , 87)	<0.0001
21	Between row cultivation	Organic	97	(94 , 99)	<0.0001	79	(67 , 89)	<0.0001
22	Between-within row	Organic	98	(95 , 99)	<0.0001	93	(85 , 98)	<0.0001
23	SoilSaver Black Oat	Organic	98	(96 ,100)	<0.0001	88	(78 , 95)	<0.0001
24	As_033 Black Oat	Organic	99	(97 ,100)	<0.0001	81	(70 , 90)	<0.0001

Table 2.14: Cutleaf-evening primrose (*Oenothera laciniata* Hill) control as influenced by herbicide and organic treatments at POST rating at Field Crops Unit in Shorter, AL and Plant Breeding Unit in Tallassee, AL in 2007 and 2008.

			2007						2008					
Treatment			FCU			PBU			FCU			PBU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%											
1	None	Control	2	(1 , 13)		0	(0 , 3)		0	(0 , 7)		0	(0 , 5)	
2	S-metolachlor/Linuron	PRE	92	(78 , 99)	<0.0001	95	(88 , 99)	<0.0001	77	(54 , 93)	<0.0001	72	(53 , 88)	<0.0001
3	Metribuzin	PRE	94	(81 ,100)	<0.0001	91	(82 , 97)	<0.0001	73	(51 , 91)	<0.0001	81	(64 , 94)	<0.0001
4	Linuron	PRE	70	(50 , 86)	<0.0001	83	(72 , 92)	<0.0001	85	(65 , 98)	<0.0001	75	(57 , 90)	<0.0001
5	S-metolachlor	PRE	45	(26 , 65)	0.0015	36	(23 , 50)	<0.0001	30	(11 , 53)	0.0182	12	(2 , 27)	0.1984
6	Pendimethalin (0.5x)	PRE	42	(23 , 62)	0.0031	14	(6 , 25)	0.0054	10	(1 , 27)	0.5673	12	(3 , 28)	0.1746
7	Pendimethalin (1x)	PRE	23	(9 , 42)	0.1595	28	(16 , 41)	<0.0001	23	(7 , 45)	0.0681	6	(0 , 19)	0.6044
8	Pendimethalin (2x)	PRE	39	(21 , 59)	0.0065	48	(34 , 62)	<0.0001	18	(4 , 40)	0.1434	8	(1 , 21)	0.4548
9	Diclosulam	PRE	96	(84 ,100)	<0.0001	94	(86 , 99)	<0.0001	85	(64 , 97)	<0.0001	91	(77 , 99)	<0.0001
10	Flumioxazin	PRE	97	(87 ,100)	<0.0001	95	(87 , 99)	<0.0001	94	(79 ,100)	<0.0001	95	(83 ,100)	<0.0001
11	Imazethapyr	PRE	85	(69 , 96)	<0.0001	92	(83 , 98)	<0.0001	48	(26 , 71)	0.0003	96	(84 ,100)	<0.0001
12	Thifensulfuron (2007)	POST	15	(4 , 32)	0.5624	31	(18 , 44)	<0.0001	N/A			N/A		
12	Carfentrazone (2008)	POST	N/A			N/A			62	(39 , 83)	<0.0001	35	(18 , 54)	0.0007
13	Fluazifop	POST	57	(37 , 76)	0.0001	50	(36 , 64)	<0.0001	66	(43 , 86)	<0.0001	28	(13 , 47)	0.0041
14	Fomesafen	POST	59	(39 , 77)	<0.0001	70	(56 , 82)	<0.0001	41	(19 , 64)	0.0018	75	(56 , 89)	<0.0001
15	2,4-DB	POST	98	(89 , 99)	<0.0001	99	(93 ,100)	<0.0001	82	(61 , 96)	<0.0001	96	(85 ,100)	<0.0001
16	Chlorimuron (2007)	POST	98	(89 ,100)	<0.0001	98	(92 ,100)	<0.0001	N/A			N/A		
16	Plant oil (2008)	POST	N/A			N/A			58	(34 , 79)	<0.0001	14	(3 , 29)	<0.0001
17	Glyphosate	POST	69	(50 , 86)	<0.0001	83	(71 , 92)	<0.0001	95	(79 ,100)	<0.0001	91	(76 , 99)	<0.0001
18	Sethoxydim	POST	45	(26 , 65)	0.0014	45	(32 , 59)	<0.0001	39	(18 , 62)	0.0028	25	(11 , 44)	0.0091
19	Flumioxazin	POST	93	(79 ,100)	<0.0001	88	(77 , 95)	<0.0001	81	(60 , 96)	<0.0001	68	(48 , 84)	<0.0001
20	Imazethapyr	POST	81	(63 , 94)	<0.0001	85	(74 , 94)	<0.0001	82	(61 , 96)	<0.0001	96	(85 ,100)	<0.0001
21	Between row cultivation	Organic	58	(38 , 77)	<0.0001	74	(61 , 86)	<0.0001	84	(64 , 97)	<0.0001	75	(57 , 90)	<0.0001
22	Between-within row	Organic	80	(61 , 93)	<0.0001	88	(77 , 95)	<0.0001	92	(75 ,100)	<0.0001	92	(79 , 99)	<0.0001
23	SoilSaver Black Oat	Organic	96	(84 ,100)	<0.0001	98	(91 ,100)	<0.0001	61	(37 , 82)	<0.0001	35	(18 , 54)	0.0007
24	As_033 Black Oat	Organic	95	(83 ,100)	<0.0001	98	(91 ,100)	<0.0001	43	(21 , 67)	0.0010	63	(44 , 81)	<0.0001

Table 2.15: Winter vetch (*Vicia villosa* Roth) control as influenced by herbicide and organic treatments at POST rating at Field Crops Unit in Shorter, AL in 2007 and 2008, and at Plant Breeding Unit in Tallassee, AL in 2007.

			2007						2008		
Treatment			FCU			PBU			FCU		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%								
1	None	Control	6	(0 , 20)		0	(0, 5)		0	(0 , 6)	
2	S-metolachlor/Linuron	PRE	97	(89 ,100)	<0.0001	97	(86 ,100)	<0.0001	96	(82 ,100)	<0.0001
3	Metribuzin	PRE	89	(76 , 97)	<0.0001	81	(63 , 94)	<0.0001	67	(43 , 87)	<0.0001
4	Linuron	PRE	94	(84 , 99)	<0.0001	72	(52 , 88)	<0.0001	76	(53 , 93)	<0.0001
5	S-metolachlor	PRE	96	(86 ,100)	<0.0001	66	(46 , 83)	<0.0001	85	(64 , 98)	<0.0001
6	Pendimethalin (0.5x)	PRE	95	(85 ,100)	<0.0001	86	(69 , 97)	<0.0001	46	(23 , 70)	0.0001
7	Pendimethalin (1x)	PRE	95	(85 ,100)	<0.0001	61	(40 , 79)	<0.0001	92	(75 ,100)	<0.0001
8	Pendimethalin (2x)	PRE	98	(90 ,100)	<0.0001	73	(53 , 88)	<0.0001	83	(61 , 97)	<0.0001
9	Diclosulam	PRE	99	(93 ,100)	<0.0001	97	(87 ,100)	<0.0001	98	(85 , 99)	<0.0001
10	Flumioxazin	PRE	83	(69 , 94)	<0.0001	74	(54 , 89)	<0.0001	90	(72 ,100)	<0.0001
11	Imazethapyr	PRE	79	(64 , 91)	<0.0001	60	(40 , 79)	<0.0001	49	(26 , 73)	<0.0001
12	Thifensulfuron (2007)	POST	98	(90 ,100)	<0.0001	89	(73 , 98)	<0.0001	N/A		
12	Carfentrazone (2008)	POST	N/A			N/A			70	(46 , 90)	<0.0001
13	Fluazifop	POST	94	(84 ,100)	<0.0001	57	(37 , 76)	<0.0001	82	(60 , 96)	<0.0001
14	Fomesafen	POST	93	(82 , 99)	<0.0001	63	(43 , 81)	<0.0001	77	(54 , 94)	<0.0001
15	2,4-DB	POST	96	(87 ,100)	<0.0001	76	(57 , 91)	<0.0001	73	(49 , 91)	<0.0001
16	Chlorimuron (2007)	POST	99	(93 ,100)	<0.0001	98	(88 ,100)	<0.0001	N/A		
16	Plant oil (2008)	POST	N/A			N/A			51	(28 , 75)	<0.0001
17	Glyphosate	POST	92	(81 , 99)	<0.0001	71	(51 , 87)	<0.0001	94	(78 ,100)	<0.0001
18	Sethoxydim	POST	93	(83 , 99)	<0.0001	53	(33 , 72)	<0.0001	54	(30 , 77)	<0.0001
19	Flumioxazin	POST	95	(84 ,100)	<0.0001	79	(61 , 93)	<0.0001	80	(57 , 95)	<0.0001
20	Imazethapyr	POST	91	(80 , 98)	<0.0001	65	(45 , 83)	<0.0001	68	(43 , 88)	<0.0001
21	Between row cultivation	Organic	96	(87 ,100)	<0.0001	91	(76 , 99)	<0.0001	94	(77 ,100)	<0.0001
22	Between-within row	Organic	95	(84 ,100)	<0.0001	94	(81 ,100)	<0.0001	94	(78 ,100)	<0.0001
23	SoilSaver Black Oat	Organic	98	(90 ,100)	<0.0001	76	(57 , 91)	<0.0001	54	(30 , 78)	<0.0001
24	As_033 Black Oat	Organic	95	(85 ,100)	<0.0001	81	(63 , 94)	<0.0001	55	(31 , 78)	<0.0001

Table 2.16: Heartwing sorrel (*Rumex hastatulus* Baldw.) control as influenced by herbicide and organic treatment at POST rating at Field Crops Unit in Shorter, AL in 2007 and 2008, and at PRE rating at Plant Breeding Unit in Tallassee, AL in 2008.

			FCU						PBU		
Treatment			2007			2008			2008		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%								
1	None	Control	3	(0 , 7)		0	(0 , 5)		4	(2 , 8)	
2	S-metolachlor/Linuron	PRE	99	(96 ,100)	<0.0001	75	(58 , 89)	<0.0001	94	(79 ,100)	<0.0001
3	Metribuzin	PRE	99	(96 ,100)	<0.0001	86	(71 , 96)	<0.0001	98	(87 ,100)	<0.0001
4	Linuron	PRE	96	(92 , 99)	<0.0001	75	(57 , 89)	<0.0001	92	(77 , 99)	<0.0001
5	S-metolachlor	PRE	92	(86 , 97)	<0.0001	37	(20 , 55)	0.0002	88	(71 , 98)	<0.0001
6	Pendimethalin (0.5x)	PRE	99	(96 ,100)	<0.0001	93	(81 , 99)	<0.0001	48	(27 , 69)	<0.0001
7	Pendimethalin (1x)	PRE	99	(96 ,100)	<0.0001	99	(92 , 99)	<0.0001	46	(26 , 68)	<0.0001
8	Pendimethalin (2x)	PRE	99	(96 ,100)	<0.0001	94	(82 ,100)	<0.0001	79	(60 , 94)	<0.0001
9	Diclosulam	PRE	99	(96 ,100)	<0.0001	99	(92 , 99)	<0.0001	98	(89 , 99)	<0.0001
10	Flumioxazin	PRE	99	(96 ,100)	<0.0001	94	(82 ,100)	<0.0001	99	(90 , 99)	<0.0001
11	Imazethapyr	PRE	99	(96 ,100)	<0.0001	44	(27 , 63)	<0.0001	97	(86 ,100)	<0.0001
12	Thifensulfuron (2007)	POST	96	(92 , 99)	<0.0001	N/A			N/A		
12	Carfentrazone (2008)	POST	N/A			33	(17 , 51)	0.0006	N/A		
13	Fluazifop	POST	98	(94 ,100)	<0.0001	20	(7 , 36)	0.0241	N/A		
14	Fomesafen	POST	95	(90 , 98)	<0.0001	14	(4 , 29)	0.1101	N/A		
15	2,4-DB	POST	93	(87 , 97)	<0.0001	20	(8 , 37)	0.0205	N/A		
16	Chlorimuron (2007)	POST	96	(91 , 99)	<0.0001	N/A			N/A		
16	Plant oil (2008)	POST	N/A			24	(11 , 42)	0.0070	N/A		
17	Glyphosate	POST	99	(96 ,100)	<0.0001	93	(80 , 99)	<0.0001	N/A		
18	Sethoxydim	POST	97	(93 , 99)	<0.0001	27	(13 , 45)	0.0033	N/A		
19	Flumioxazin	POST	98	(95 ,100)	<0.0001	46	(28 , 64)	<0.0001	N/A		
20	Imazethapyr	POST	97	(94 ,100)	<0.0001	80	(63 , 92)	<0.0001	N/A		
21	Between row cultivation	Organic	97	(92 , 99)	<0.0001	89	(75 , 98)	<0.0001	73	(53 , 90)	<0.0001
22	Between-within row	Organic	99	(96 ,100)	<0.0001	96	(87 ,100)	<0.0001	84	(65 , 96)	<0.0001
23	SoilSaver Black Oat	Organic	98	(94 ,100)	<0.0001	29	(14 , 47)	0.0017	29	(12 , 50)	0.0234
24	As_033 Black Oat	Organic	98	(95 ,100)	<0.0001	23	(10 , 40)	0.0100	20	(6 , 39)	0.3202

Table 2.17: Corn spurry (*Spergula arvensis* L.) control as influenced by herbicide and organic treatment at the POST rating at Field Crops Unit in Shorter, AL in 2008.

Treatment			2007			2008		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
					%			
1	None	Control	0	(0 , 6)		0	(0 , 6)	
2	S-metolachlor/Linuron	PRE	98	(89 , 99)	<0.0001	94	(81 ,100)	<0.0001
3	Metribuzin	PRE	96	(85 ,100)	<0.0001	74	(55 , 90)	<0.0001
4	Linuron	PRE	97	(87 ,100)	<0.0001	83	(65 , 95)	<0.0001
5	S-metolachlor	PRE	99	(91 , 99)	<0.0001	57	(37 , 77)	<0.0001
6	Pendimethalin (0.5x)	PRE	99	(90 , 99)	<0.0001	78	(59 , 93)	<0.0001
7	Pendimethalin (1x)	PRE	99	(90 , 99)	<0.0001	98	(88 ,100)	<0.0001
8	Pendimethalin (2x)	PRE	99	(90 , 99)	<0.0001	91	(76 , 99)	<0.0001
9	Diclosulam	PRE	88	(72 , 98)	<0.0001	79	(61 , 93)	<0.0001
10	Flumioxazin	PRE	99	(90 , 99)	<0.0001	94	(80 ,100)	<0.0001
11	Imazethapyr	PRE	88	(72 , 98)	<0.0001	42	(23 , 63)	0.0003
12	Thifensulfuron (2007)	POST	43	(23 , 64)	0.0003	N/A		
12	Carfentrazone	POST	N/A			23	(8 , 42)	0.0292
13	Fluazifop	POST	80	(61 , 94)	<0.0001	7	(0 , 21)	0.6489
14	Fomesafen	POST	22	(7 , 41)	0.0396	14	(3 , 31)	0.1718
15	2,4-DB	POST	39	(20 , 59)	0.0008	6	(0 , 19)	0.7628
16	Chlorimuron (2007)	POST	93	(78 ,100)	<0.0001	N/A		
16	Plant oil (2008)	POST	N/A			26	(10 , 45)	0.0160
17	Glyphosate	POST	88	(72 , 98)	<0.0001	94	(81 ,100)	<0.0001
18	Sethoxydim	POST	71	(50 , 87)	<0.0001	7	(0 , 20)	0.6549
19	Flumioxazin	POST	98	(87 ,100)	<0.0001	80	(62 , 94)	<0.0001
20	Imazethapyr	POST	86	(68 , 97)	<0.0001	34	(17 , 55)	0.0021
21	Between row cultivation	Organic	87	(70 , 98)	<0.0001	81	(63 , 94)	<0.0001
22	Between-within row	Organic	75	(55 , 90)	<0.0001	85	(67 , 96)	<0.0001
23	SoilSaver Black Oat	Organic	94	(81 ,100)	<0.0001	8	(0 , 22)	0.5735
24	As_033 Black Oat	Organic	93	(80 ,100)	<0.0001	17	(5 , 35)	0.1036

Table 2.18: Corn spurry (*Spergula arvensis* L.) control as influenced by herbicide and organic treatment by rating at Plant Breeding Unit in Tallassee, AL in 2007 and 2008.

			PBU 2007						PBU 2008					
Treatment			PRE			POST			PRE			POST		
No	Name	Class	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*	Mean	95% CI	Dunnett's *P-value*
			%											
1	None	Control	35	(27 , 44)		0	(0 , 3)		4	(2 , 7)		0	(0 , 6)	
2	S-metolachlor/Linuron	PRE	99	(90 , 98)	<0.0001	99	(94 ,100)	<0.0001	99	(89 , 98)	<0.0001	97	(84 ,100)	<0.0001
3	Metribuzin	PRE	99	(89 , 98)	<0.0001	86	(74 , 95)	<0.0001	96	(83 ,100)	<0.0001	85	(65 , 98)	<0.0001
4	Linuron	PRE	99	(90 , 98)	<0.0001	99	(94 ,100)	<0.0001	99	(88 , 99)	<0.0001	93	(77 ,100)	<0.0001
5	S-metolachlor	PRE	98	(87 , 99)	<0.0001	99	(93 ,100)	<0.0001	76	(54 , 93)	<0.0001	63	(40 , 84)	<0.0001
6	Pendimethalin (0.5x)	PRE	98	(87 , 99)	<0.0001	99	(94 ,100)	<0.0001	97	(84 ,100)	<0.0001	96	(82 ,100)	<0.0001
7	Pendimethalin (1x)	PRE	94	(80 ,100)	<0.0001	99	(94 ,100)	<0.0001	94	(79 ,100)	<0.0001	92	(74 ,100)	<0.0001
8	Pendimethalin (2x)	PRE	98	(87 , 99)	<0.0001	99	(94 ,100)	<0.0001	98	(88 , 99)	<0.0001	96	(81 ,100)	<0.0001
9	Diclosulam	PRE	99	(89 , 98)	<0.0001	97	(90 ,100)	<0.0001	95	(81 ,100)	<0.0001	91	(73 , 99)	<0.0001
10	Flumioxazin	PRE	99	(90 , 98)	<0.0001	99	(93 ,100)	<0.0001	99	(89 , 98)	<0.0001	98	(86 , 99)	<0.0001
11	Imazethapyr	PRE	98	(86 , 99)	<0.0001	97	(89 ,100)	<0.0001	90	(73 , 99)	<0.0001	97	(83 ,100)	<0.0001
12	Thifensulfuron (2007)	POST	N/A			98	(92 ,100)	<0.0001	N/A			N/A		
12	Carfentrazone (2008)	POST	N/A			N/A			N/A			55	(32 , 77)	0.0001
13	Fluazifop	POST	N/A			65	(49 , 78)	<0.0001	N/A			6	(0 , 22)	0.8047
14	Fomesafen	POST	N/A			37	(23 , 52)	<0.0001	N/A			19	(5 , 41)	0.1242
15	2,4-DB	POST	N/A			60	(44 , 74)	<0.0001	N/A			5	(0 , 19)	0.9214
16	Chloriumron (2007)	POST	N/A			98	(92 ,100)	<0.0001	N/A			N/A		
16	Plant oil (2008)	POST	N/A			N/A			N/A			32	(13 , 56)	0.0124
17	Glyphosate	POST	N/A			92	(82 , 99)	<0.0001	N/A			98	(85 , 99)	<0.0001
18	Sethoxydim	POST	N/A			84	(71 , 94)	<0.0001	N/A			45	(23 , 68)	0.0010
19	Flumioxazin	POST	N/A			93	(83 , 99)	<0.0001	N/A			81	(60 , 96)	<0.0001
20	Imazethapyr	POST	N/A			88	(76 , 96)	<0.0001	N/A			96	(81 ,100)	<0.0001
21	Between row cultivation	Organic	5	(0 , 19)	0.0088	88	(76 , 96)	<0.0001	55	(32 , 77)	<0.0001	83	(62 , 96)	<0.0001
22	Between-within row	Organic	6	(0 , 20)	0.0149	93	(82 , 99)	<0.0001	86	(67 , 98)	<0.0001	95	(80 ,100)	<0.0001
23	SoilSaver Black Oat	Organic	59	(36 , 80)	0.4856	99	(94 ,100)	<0.0001	2	(1 , 13)	1.0000	7	(0 , 24)	0.7208
24	As_033 Black Oat	Organic	45	(23 , 67)	0.9993	99	(93 ,100)	<0.0001	0	(5 , 5)	0.7686	44	(22 , 68)	0.0012

III. EFFECTS OF WEED MANAGEMENT PRACTICES ON CROP INJURY AND YIELD IN WHITE LUPIN (*LUPINUS ALBUS* L.)

Abstract

White lupin (*Lupinus albus* L.) is one of four agronomically important lupin species world wide. Today white lupin is used as human food, animal feed and as cover a crop in conservation agriculture. The availability of winter-type cultivars are reasons for the major interest in white lupin in the southeastern United States. Winter-type *Lupinus albus* L. cultivars can be used in winter grain rotations and as mid-winter forage for ruminants. White lupins are poor weed competitors during early establishment, which makes effective weed control necessary. A two-year experiment was established at two sites at E.V. Smith Research Center of the Alabama Agricultural Experiment Station in 2007 and 2008. The weed management schemes evaluated included ten pre-emergence (PRE) and nine post-emergence (POST) herbicide treatments as well as cultural treatments (two mechanical and two companion crop living mulch weed control measures). The objective of this experiment was to investigate the use of weed management practices and their effect on white lupin injury, plant density and yield. It was found that the PRE herbicides diclosulam and flumioxazin resulted in unacceptable crop injury and subsequent yield loss in 2007 and 2008. The POST herbicides

thifensulfuron and chlorimuron caused complete crop injury (death) of all three cultivars in 2007. Hence these herbicides were excluded in study year 2008. Application of glyphosate lead to inacceptable crop injury and significant yield reduction, but did not significantly reduce crop density.

Introduction

Lupinus albus L., a species of the botanical family of Fabaceae, is one of the four major economical important large-seeded lupin species currently grown worldwide. The other three species are yellow lupin (*L. luteus* L.), narrowleafed or blue lupin (*L. angustifolius* L.), and Andean lupin (*L. mutabilis* Sweet) (Bhardwaj, 2002).

Due to the availability of winter-type cultivars white lupin is of particular interest in the southeastern USA. This species was grown successfully in the southeastern United States from the 1930s to the 1950s as a cover crop and for the fixation of nitrogen (Roberson, 1991). After the 1950s white lupin production declined due to loss of government support, freeze damage in two consecutive years and the increased availability of inorganic fertilizers (Payne et al., 2004; van Santen and Reeves, 2003; Noffsinger and van Santen, 2005). Recently, there has been renewed interest in this crop in the United States and Canada as an alternative legume crop and for its yield potential. Research has been conducted to improve seed quality, genetic improvement for cold, disease and pest tolerance, and to determine best management cultural practices (Faluyi, et al., 2000; Payne et al., 2004; Noffsinger and van Santen, 2005). Winter-type *L. albus*

L. cultivars increased lint yield in cotton (*Gosssypium hirsutum* L.) when used in a winter grain rotation (Noffsinger and van Santen, 2005). Traditionally, white lupin has been used as livestock feed especially as mid-winter forage for ruminants due to a forage quality similar to that of alfalfa (Noffsinger and van Santen, 2005). Additionally, *L. albus* L. is used as human food and winter cover crop in conservation agriculture (Hill, 1990; Hill, 2005; Noffsinger and van Santen, 2005).

Due to a slow canopy development white lupin is a poor weed competitor during early establishment. Effective weed control is necessary to reduce the competition for water, nutrients and lights among *L. albus* L. and weed species (Putnam et al., 1989; Poetsch, 2006).

Research has been conducted to evaluate weed control treatments in white lupin that successfully control local weeds and would not cause crop injury and subsequent yield loss. Yield reduction was found to be related to crop injury and stand reductions in soybean (Taylor-Lovell et al., 2001). Knott (1996) found that lupins are especially sensitive to post-emergence herbicides (POST). In a study to evaluate the tolerance of autumn-sown determinate white lupin to herbicides Knott (1996) found that the POST aryloxyphenoxypropionate (fop) fluazifop did not damage white lupin, but that Sulfonlyurea herbicides such as metsulfuron did. Successful pre-emergence (PRE) herbicide treatments that resulted in no crop damage were the dinitroaniline herbicide pendimethalin (Mitich et al., 1989; Knott, 1996). Pendimethalin in combination with the triazine herbicide metribuzin did not cause crop damage (Knott, 1996). Metribuzin at twice the normal application rate resulted in unacceptable yield loss (Knott, 1996).

Similar results were observed by Ivany and McCully in 1994. It was found that increasing application rates of metribuzin resulted in increased sweet white lupin injury (1-29% crop injury). Metolachlor, a chloroacetamide herbicide, was also evaluated and it did not damage lupin (Ivany and McCully, 1994). A mixture of metolachlor with linuron (a substituted Urea herbicide) also was safe on sweet white lupin (0% crop injury). Additionally, it was found that the herbicide imazethpyr provided successful weed control and was safe on white lupin when applied PRE. POST application of imazethapyr resulted in 15% to 24% crop injury and yield reduction while giving good weed control (Ivany and McCully, 1994). Penner et al (1993) found that imazethapyr caused crop damage of 35% to 60% when applied either POST or PRE.

Hagemann Wiedenhoeft and Ciha (1987) reported that 2,4-DB, a carboxy acid, applied at the 1-2 leaf stage injured white lupin to 99 to 100%, whereas the rates applied at the 3-4 leaf stage only injured white lupin to 59 to 73%. Furthermore it was found that pendimethalin (PRE) did not injure white lupin, but that metribuzin caused of 98% to 100% injury. The POST-applied herbicides fluazifop and sethoxydim (a cyclohexanedione herbicide) were safe on white lupin and only caused 1% to 20% injury (Hagemann Wiedenhoeft and Ciha, 1987).

Penner et al. (1993) also found that the PRE-applied pendimethalin, metolachlor and linuron as well as the POST-applied fluazifop and sethoxydim caused 0% crop damage. The PRE metribuzin injured sweet white lupin to 61% and the POST 2,4-DB caused 17% crop injury in the greenhouse study conducted by Penner et al. (1993).

Due to the high costs of hand hoeing as a weed management tool, it is used primarily in high value crops or as supplement to other weed control practices. It is successful on weed seedlings and annual/biennial weeds (Anderson, 1996). Organic production, an important sector in US agriculture, requires the use of mechanical weed control practices. To be certified as an organic farm the producer has to follow the guidelines of the National Organic Program (NOP) from the seeds used to grow the crops to the final product. The NOP is a program developed by the United States Department of Agriculture and limits the use of synthetic herbicides and therefore other weed control practices such as hoeing are necessary (Cornell Cooperative Extension Publication, 2009). It was found that lentil yield was higher in hand-hoed plots than in plots in which herbicides such as linuron and metribuzin were used (Sandhu et al., 1991).

Cover crops, also an important weed management tool in organic farming and conservation agriculture, have the benefits to lower fertilizer costs, reduce soil erosion, improve soil moisture, enhance organic matter, break pest cycles and reduce the use of pesticides (herbicides, insecticides and fungicides) (Bowman et al., 1998). Cover crops out-compete weeds or reduce weed pressure by allelopathy (Anderson, 1996). A relatively new cover crop for the Southeastern USA is black oat (*Avena strigosa* Schreb.), a cool-season annual cereal that has been used successfully for many years as a cover crop for soybean [*Glycine max* (L.) Merr.] in Brazil (Bowman et al., 1998). Black oat is promising due to its exceptional allelopathic activity and large biomass production (Price et al., 2008). Even though black oat is successfully used as a weed management tool in soybean, cotton shows sensitivity to its allelopathic activity (CTAHR, 11-07-2008).

Only three herbicides are currently registered for the use in *Lupinus* ssp: carfentrazone-ethyl, *S*-metolachlor and glyphosate (Crop Protection Reference, 2007). The objective of this experiment is to investigate the use of various weed management practices and their effect on white lupin injury, plant density and yield.

Materials and Methods

A two year experiment to investigate the effect of weed management practices on crop injury in *L. albus* L. was established at two test sites at E.V. Smith Research Center of the Alabama Agricultural Experiment Station in October 2007 and 2008 respectively.

Treatment and experiment design

The experiment had a 2 (year) x 2 (location) x 3 (cultivar) x 4 (block) x 24 (weed control) factorial arrangement of treatment and design factors. The two locations of the experiment were the Field Crops Unit (FCU), near Shorter, AL (32.42 N, 85.88 W) and the Plant Breeding Unit (PBU), Tallassee, AL (32.49 N, 85.89 W). At FCU the field experiment was established on a Compass loamy sand (a coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults with a loamy sand surface structure). At PBU the experiment was conducted on a Wickham sandy loam (a fine-loamy, mixed, semiactive, thermic Typic Hapludults with a sandy loam surface structure). The three lupin cultivars used in the experiment were AU Homer (a high-alkaloid, indeterminate cover crop type), AU Alpha (a low-alkaloid, indeterminate forage type), and ABL 1082 (a low-alkaloid, determinate grain type experimental cultivar). The experimental design was a randomized complete block design (r = 4) nested within each year x location x cultivar combination. The weed control factor had 24 levels: one non-treated control, 10 PRE-applied herbicids, nine POST-applied herbicides, two mechanical (hand hoed) weed control treatments, as well as two cultural (living mulch) weed control treatments (Table 2.01).

Crop management

Inoculated lupin was seeded in 4 row plots with a John Deer® 1700 four-row vacuum planter with a row spacing of 90 cm at a depth of 1.25 cm in October 2007 and October 2008. The seeding density was 19 seeds m^{-1}. A smooth seedbed was prepared one to two weeks prior to planting in 2007. In 2008, the cultivars were planted on raised beds prepared with a KMC 4 row ripper/bedder due to concerns about water logging at both locations. The plot length was 7.5 m at PBU, and 7.5 m and 6 m at FCU in 2007 and 2008, respectively. The PRE herbicide treatments were applied one day after planting in both years. Application of POST herbicides followed 13 (2007) to 16 (2008 due to heavy rainfall) weeks after planting. The cultural control treatments, cv. SoilSaver and As_033 (a selection from PI 436103) black oat (*Avena strigosa* Schreb.), were sown one (2007) to seven days (2008) after seeding of the lupin crop. The mechanical weed control treatments, between row only cultivation and between and within row cultivation, were used twice four (2007) to six (2008) weeks after planting and 18 to 20 (2 blocks at the PBU test site due to heavy rains) weeks after planting.

Crop Injury Ratings

Crop injury ratings were taken on a scale from 0 to 10, where 0 is equivalent to no injury/alive, and 10 is equivalent to complete crop injury/dead. Two crop injury ratings per treatment/plot were taken at both locations in 2007. Three crop injury ratings per treatment/plot were taken at both locations in 2008. Each treatment was rated based on the injury in the non-treated control in block one of every year* location*cultivar combination. The non-treated control was considered to have 0 crop injury. In study year 2007 the first injury rating was taken after only the PRE treatments were applied (3 weeks after PRE application). The second rating was taken 2 weeks after the POST treatments were applied. In study year 2008 the first two ratings were taken after only the PRE treatments were applied (4 and 12 weeks after PRE application). The third rating was taken 2 weeks after the POST treatments were applied.

Stand Count

Stand counts were taken to determine the plant density. Plants in the two center rows of each four row plot were counted along a three meter PVC pole. Three stand counts were taken in year 2007. The first count was taken 6 weeks after PRE and the second count 11 weeks after PRE. The third and final stand count was taken 3 weeks after POST treatments were applied. In 2008 two stand counts were taken 4 weeks and 8 weeks after PRE treatments were applied. Due to heavy rains after POST application in study year 2008 the plots were inaccessible for stand counts.

Yield

In study year 2007/2008 plots at PBU and FCU were harvested on June 17, 2008. In study year 2008/2009 plots at FCU were harvested on June 16, 2009 and at PBU on June 29, 2009 due to differences in reaching maturity at both locations. To determine the plot yield as influenced by weed management practice the two center rows of each plot were harvested with a 2 row/10 ft Massey Ferguson plot combine. The seed of each plot was bagged separately. The seeds of each bag were weighed and the weight in kg was noted. Once the plot yield was noted a test weight (subsample) of each bag was taken in g per volume (352ml cup). Each subsample was individually bagged and with a seed counter (Hoffman Manufacturing Inc.) 500 seeds were counted and the thousand seed mass determined.

Statistical analysis

Generalized linear mixed models procedures as implemented in SAS® PROC GLIMMIX were used to analyze crop injury, stand count and yield data. Treatments and location were considered fixed effects. Replicates were considered random. Statistical significance was declared at Dunnett's $P < 0.1$. Crop injury data were modeled using arcsine transformed data and then analyzed with a normal distribution function. Stand density (plants m^{-2}), grain yield (kg ha^{-1}), test weight (kg $100L^{-1}$) and seed mass (mg per seed) were analyzed as normally distributed.

Results and Discussion

Crop injury

ABL 1082. The three-way interaction (Location*Treatment*cultivar) was non-significant (α=0.1). However the two-way interactions (Treatment*Cultivar and Location*Treatment) were significant. In the first rating (3 weeks after PRE herbicide application) in 2007 none of the PRE herbicides, cultivation treatments and black oat cultivars injured the cultivar when compared to the non-treated control in FCU and PBU (Table 3.01). At the same rating (4 weeks after PRE herbicide application) in 2008 the PRE applied *S*-metolachlor/linuron mixture and metribuzin lead to crop injury rating of 1 at FCU and PBU. This was significantly higher injury than the non-treated control. At FCU diclosulam resulted in crop injury of 1, which was significant in comparison to the control group. Additionally, at PBU the highest application rate of pendimethalin and flumioxazin resulted in crop injury of 1 and 2.5, respectively. Lowest crop injury of 0 was observed at FCU and PBU in 2008 with between row cultivation. At PBU all organic treatments resulted in no injury at all that year (Table 3.01).

In 2008 only, a second crop injury rating was taken and showed that metribuzin and diclosulam injured 1.7 and 5, respectively at FCU. This is significantly higher than the non-treated control (Table 3.02). At PBU the PRE herbicides diclosulam (1.35), the *S*-metolachlor/linuron mixture (1.46), imazethapyr (1.68) and flumioxazin (2.62) resulted in significantly higher crop injury when compared to the non-treated control. No crop injury was observed when between-within row cultivation as well as both black oat cultivars were used (Table 3.02).

Final crop injury rating was conducted 2 weeks after POST application at both locations and years. Over the course of the study injury caused by PRE applied herbicides became more apparent. On the injury scale from 0 to 10, diclosulam injured to 9.0 and 6.0 at FCU and PBU, respectively in 2007 (Table 3.03). In 2008 this herbicides caused crop injury of 8.8 and 5.3. Flumioxazin (PRE applied) injury can be found at 6.3 at PBU in 2008. In general, the POST herbicides injured ABL 1082 more severely than the PRE herbicides (Table 3.03). In 2007, plant death was caused by POST herbicides thifensulfuron (10) and chlorimuron (9.94) at both locations. Due to these severe crop losses both of these herbicides were substituted by carfentrazone and plant oil in 2008. In 2007, a mean injury of 8 was caused by fomesafen. Glyphosate caused injury of 6 at FCU in 2007, and at both locations in 2008 (Table 3.03). A mean crop injury of 0 was observed when between row cultivation was used at FCU in 2008.

AU Alpha. The three-way interaction (location*treatment*cultivar) was non-significant. However the two-way interactions (treatment*cultivar and location*treatment) were significant. At the first injury rating (3 weeks after PRE application) in 2007, no significant crop injury was observed at either FCU or PBU (Table 3.04). In 2008 the first rating was done 4 weeks after PRE application. Crop injury of 1.5 at both locations was caused by diclosulam. Flumioxazin resulted in 2.2 injury. Between row and between-within row cultivation did not injure the cultivar at both locations (Table 3.04).

A second rating after PRE application (12 weeks) in 2008 only, showed that all three application rates of pendimethalin caused no or negligible injury at FCU and PBU (Table 3.05). The same was observed for both cultivation and black oat treatments. Mean injury of 3.7 and 2.7 was caused by diclosulam at FCU and PBU, respectively. The PRE applied flumioxazin and imazethapyr resulted in 1.7 injury (Table 3.05).

The final crop injury rating after POST herbicide application showed that injury of the PRE applied herbicide diclosulam became more significant over the course of the study. In 2007 diclosulam caused 9.9 injury at FCU, but was not significantly higher than the non-treated control at PBU (Table 3.06). The highest application rate of pendimethalin caused significant injury (4.0) at FCU only that year. Complete crop injury was caused by POST applied thifensulfuron (9.5 and 9.9) and chlorimuron (10.0 and 9.6) at FCU and PBU. Based on the injury scale high injury was observed at FCU when the POST applied flumioxazin (7.8), fomesafen (6.8) and glyphosate (5.9) were used (Table 3.06). In study year 2008, diclosulam was the only PRE applied herbicide that caused severe crop injury (9.00) at both locations at the final rating (Table 3.06). Injury of 4.5 and 5.3 was caused by glyphosate at FCU and PBU, respectively. Fomesafen resulted in 3.2 injury at FCU that year. The POST applied imazethapyr and black oat cultivars SoilSaver and As_033 caused either no or negligible injury of this cultivar at FCU in 2008 (Table 3.06).

AU Homer. The three-way interaction (location*treatment*cultivar) was non-significant. However the two-way interactions (treatment*cultivar and location*treatment) were significant. At the first crop injury rating in 2007, all PRE applied herbicides, cultivation and black oat treatments resulted in significantly injury equivalent to the non-treated control (Table 3.07). Similar results were observed at the same rating in 2008 with the exception of the PRE applied flumioxazin and imazethapyr. At PBU both of these herbicides caused mean crop injury of 1.7 and 1, respectively. This is not severe, but nonetheless significantly higher than the non-treated (3.07). At FCU however, imazethapyr did not injure this cultivar. The organic treatments caused no crop injury at PBU at the first rating at PBU.

In 2008, at the second crop injury rating, it was found that linuron and all organic treatments caused either no or negligible injury (Table 3.08). With mean crop injury of 4.8 diclosulam severely injured AU Homer at FCU. At PBU mean crop injury by this herbicide was 1.7, which however is significantly higher than the injury observed in the non-treated control. Both PRE applied flumioxazin (1.2) and *S*-metolachlor (1.2) caused significantly higher crop injury than the non-treated control (Table 3.08).

Final crop injury ratings are shown in Table 3.09. In 2007, the PRE applied diclosulam caused severe injury of 8.5 and 6.8 at FCU and PBU, respectively. Again it can be seen that the POST applied herbicides resulted in more injury in 2007. Total white lupin injury was caused by thifensulfuron (10.0 and 9.4) and chlorimuron (10.0 and 9.7) at FCU and PBU. Mean crop injury of 6 was caused by the POST applied flumioxazin at both locations which is significant in comparison to the non-treated control. Fomesafen only caused severe crop injury (7.4) at FCU that year. Metribuzin, linuron, the *S*-metolachlor/linuron mixture as well as the organic treatments were safe for use in cultivar AU Homer in 2007. In 2008, diclosulam and glyphosate were the only herbicides that caused crop injury that was significantly higher than the injury observed in the non-treated control (Table 3.09). Diclosulam caused mean crop injury of 7.6 and 7.3 at FCU and PBU, respectively. Glyphosate only caused significant crop injury (7.8) at PBU. No or negligible AU Homer injury was caused by the lowest application rate of pendimethalin and 2,4-DB at FCU.

Diclosulam which is applied either preplant incorporated (PPI) or PRE is registered in soybean [*Glycine max* (L.) Merr.] and peanut (*Arachis hypogaea* L.), was found to cause severe injury of more than 80% in non-imidazolinone resistant corn (*Zea mays* L.) by Bailey and Wilcut (2003). Injury ratings shortly after PRE application detected marginal injury. However later ratings the following spring revealed higher injury of all three white lupin cultivars (>7). The lack of early injury may be due to the slow acting nature of AHAS inhibitors and/or reduced growth of lupin after PRE application. Based on our results it is suggested to avoid the application of this herbicide in white lupin production. The good weed control results observed (Chapter II) with this herbicide are misleading if crop injury is not also taken into consideration.

PRE applied flumioxazin behaved similarly to diclosulam in that highest injury was observed at the final rating across all three cultivars. Taylor-Lovell et al. (2001) observed that phytotoxicity of flumioxazin to soybean increases with higher soil moisture. This may be an explanation why crop injury by this herbicide was higher at FCU in 2007. Due to the proximity of the study site to woody areas, half of the plots had good moisture throughout the year. Study year 2008 was a wet year and hence soil moisture was high throughout the year. Therefore flumioxazin application in white lupin should be done carefully in years with low soil moisture or should be avoided all together.

Metribuzin only injured AU Alpha significantly at one location at the final rating (<5). The results of this study suggest that metribuzin causes minimal white lupin injury. Knott (1996) found simimlar results. In his study to investigate the tolerance of determinate lupins sown in fall to herbicides, metribuzin had crop injury ratings ranging from no injury to severe injury. Based on our observations it should be avoided to use this herbicide in cultivar AU Alpha. Our results indicate that white lupin cultivars have variable tolerance to metribuzin similar to those observed in soybean by Hardcastle (1979).

Glyphosate is registered POST directed application in lupin in the USA (Crop Protection Reference, 2007). Even though this herbicides was applied accordingly crop injury in all cultivars ranged from 4 to 7. This may be caused by drift. Since the herbicide were applied with a backpack sprayer it is possible that spray height was not uniform. With increased care during the application process (no wind) this herbicides may be used in white lupin production.

Thifensulfuron caused complete kill of all three cultivars at FCU and PBU in 2007. Hence it was not included again in study year 2008. Thifensulfuron is registered for use in soybean, but it was found that phytotoxicity varied in soybean cultivars (Nelson et al., 2002).

Chlorimuron behaved very similar to thifensulfuron. When applied POST caused complete kill of all three cultivars in 2007. Therefore it was not included in study year 2008. Research done by Knott (1996) suggests that sulfonylurea herbicides such metsulfuron cause variable crop injury in white lupin ranging from no to injury above acceptable when applied at the normal field rate and twice the normal field rate. Our results suggest that thifensulfuron and chlorimuron should not be used in white lupin.

The fact that none of the cultivation treatments (between row and between-within row) resulted in crop injury level above 1 indicates that hand hoeing is very selective and careful. However it is labor-intense and therefore hard to accomplish on a larger scale. Both black oat cultivars did not cause crop injury above score 1 either. This may indicate that white lupin is not sensitive to the allelopathic activity of black oat as compared to cotton (CTAHR, 11-07-2008).

In general it can be said that unless a weed control treatment caused severe crop injury of 4 or more its use in the tested white lupin cultivars is safe. With the exception of imazethapyr, all of the ALS inhibitors caused severe crop injury and should not be used in white lupin production. It can be concluded that the PRE-applied herbicides, excluding for the above mentioned exceptions, were generally safer than the POSTs, which confirms observations made by Dittman (1999).

Plant density

In 2008, the two-way interaction location*treatment was significant for both stand counts. Plant density (plants m^{-2}) was first determined 6 and 4 weeks after PRE application in 2007 and 2008, respectively. Results show that the non-treated control groups in 2007 had a plant density of 11 and 8 plants m^{-2} at FCU and PBU, respectively. The non-treated control groups in 2008 had a plant density of 10 plants per m^{-2} at FCU and 11 plants m^{-2} at PBU (Table 3.10). It was found that none of the PRE herbicides and organic weed control treatments significantly reduced plant density as compared to the non-treated control at FCU and PBU in 2007. With the exception of flumioxazin (7.4 plants m^{-2} at PBU), the same results were obtained in 2008 (Table 3.10).

Based on the second stand count 11 and 8 weeks after PRE application in 2007 and 2008 respectively, plant density results for the non-treated control groups were 10.6 plants m^{-2} at FCU and 8.1 m^{-2} at PBU in 2007, and 9.6 m^{-2} at FCU and 9.3 m^{-2} at PBU in 2008 (Table 3.11). This is a slight plant density reduction in study year 2008 as compared to the first stand count. In 2007, none of the PRE herbicide and cultivation and black oat treatments caused significant plant density reduction as compared to the non-treated control. However, at PBU the black oat cultivar SoilSaver with a density of 7.4 m^{-2} had the lowest density as compared to the control (Table 3.11). In 2008, with the exception of diclosulam and flumioxazin, none of the PRE herbicides and the organic treatments reduced plant density. Diclosulam had with 7.2 plants m^{-2} the lowest plant density at FCU that year. At PBU, flumioxazin had a plant density of 4.7 plants m^{-2} which was a significantly lower than that of the non-treated control (Table 3.11).

Taylor-Lovell et al. (2001) reported that soybean density decreased with an increasing rate of flumioxazin and that even the field rate of flumioxazin reduced crop density 20 to 50%. The PRE applied flumioxazin reduced white lupin density up to 50% as well. It was interesting to note that the reduction in lupin density was observed primarily in study year 2008. This coincides again with a statement made by Taylor-Lovell et al. (2001) that phytotoxicity potential of flumioxazin increases with higher soil moisture. Diclosulam only reduced stand counts significantly at FCU in 2008. Stand count reductions by diclosulam seem to be not as closely related to crop injury as for instance by flumioxazin.

Due to heavy rains after POST herbicide application in study year 2008 the plots were inaccessible for additional stand counts. However in 2007 it was possible to obtain this data. Due to the fact that the three-way interaction of location*treatment*cultivar was significant, plant density for each cultivar is presented separately. The plant density of the non-treated control groups of cultivar ABL 1082 was 8.8 plants m^{-2} at FCU and 9.2 m^{-2} at PBU (Table 3.12). None of the PRE herbicides, with the exception of diclosulam at FCU (5.6 m^{-2}) reduced plant density of ABL 1082 significantly. The density reduction of ABL 1082 by diclosulam can be a subsequent effect of the crop injury induced by this herbicide. POST applied thifensulfuron and chlorimuron were the only POST herbicides that caused significant density reduction of this cultivar at both locations. Both herbicides had a density of 0.0 plants m^{-2} (Table 3.12). None of the cultivation and black oat treatments caused plant density reductions that were significant. However, at FCU between row cultivation had a higher density (10.0 plants m^{-2}) than the control.

Very similar results were obtained for cultivar AU Alpha. As can be seen in Table 3.13 plant, density of the non-treated control was 11.1 plants m^{-2} at FCU and 5.6 m^{-2} at PBU. With the exception of diclosulam at FCU, none of the PRE herbicides caused significant reduction of AU Alpha density. Diclosulam had a density of 4.9 m^{-2}. This coincides with the crop injury results mentioned previously. In case of AU Alpha crop injury by diclosulam seems to cause crop density reduction. The only POST applied herbicides that reduced plant density of this cultivar significantly were thifensulfuron and chlorimuron. Thifensulfuron had a density of 2.5 plants m^{-2} at FCU and 0.2 m^{-2} at PBU. At both locations chlorimuron caused a density of 0 plants m^{-2}. Neither the cultivation treatments nor the both black oat cultivars caused significant AU Alpha plant density reduction (Table 3.13). Plant density of this cultivar was generally low at PBU.

Plant density of the non-treated control of AU Homer was 9.9 plants m^{-2} at FCU and 8.5 m^{-2} at PBU. None of the PRE herbicides and organic weed control treatments caused significant density reductions (Table 3.14). All POST herbicides, with the exception of thifensulfuron and chlorimuron, did not reduce or increase density of AU Homer significantly. Both herbicides reduced plant density to <0.1 plants m^{-2} at both locations. At FCU the POST applied imazethapyr (11.2 m^{-2}) had a higher density than the non-treated control.

Based on the results that were obtained at the POST stand count in 2007, it is obvious that thifensulfuron and chlorimuron caused severe plant density reduction and should not be used in these *Lupinus albus* L. cultivars. These stand count reductions caused by thifensulfuron and chlorimuron are a subsequent effect of the crop injuries observed in the previous section.

Grain yield

Mean grain yields (kg ha^{-1}) were much higher for all three cultivars in 2008 as compared to 2007 (Table 3.15). The grain type cultivar ABL 1082 yielded highest of the three cultivars in both years. The interaction of treatment and cultivar was statistically significant.

ABL 1082. The non-treated control had a mean yield of 1337 kg ha^{-1} in 2007 and of 2074 kg ha^{-1} in 2008. In both years none of the PRE herbicides, with the exception of diclosulam, reduced yield. Diclosulam caused yield losses of nearly 950 kg ha^{-1} in 2007 and 1430 kg ha^{-1} in 2008 (Table 3.15). Due to the fact that thifensulfuron and chlorimuron had yields of 0 kg ha^{-1} in 2007, these two POST applied herbicides were replaced by carfentrazone and plant oil in 2008. Plots in which plant oil was applied yielded higher (2195 kg ha^{-1}) than the non-treated control. This increase was non-significant. In 2008 glyphosate was the only POST applied herbicide that caused significant yield losses of 1700 kg ha^{-1}. Plots in which between row cultivation was used yielded nearly 220 kg ha^{-1} higher than the non-treated control that same year. None of the organic treatments significantly reduced mean grain yield of cultivar ABL 1082.

AU Alpha. Mean grain yields of 702 kg ha^{-1} in 2007 and 1957 kg ha^{-1} were obtained in the non-treated control (Table 3.15). In 2007, none of the PRE and POST applied herbicides as well as the organic treatments reduced yield. However the POST herbicides thifensulfuron and chlorimuron yielded 218 kg ha^{-1} and 0 kg ha^{-1}, respectively. In 2008, diclosulam with a mean grain yield of 210 kg ha^{1} was the only PRE herbicide that reduced mean yield of this cultivar significantly. Similarly glyphosate (mean grain yield 735 kg ha^{-1}) was the only POST herbicide that caused significant yield reduction. Of the organic weed control treatments, between row cultivation (1722 kg ha^{-1}) affected mean grain yield the least as compared to the non-treated control.

AU Homer. The non-treated control had mean grain yields of 555 kg ha^{-1} in 2007 and 1219 kg ha^{-1} in 2008 (Table 3.15). None of the PRE and POST herbicide, and organic treatments significantly reduced or increased yield as compared to the control in 2007. However yield obtained from plots treated with diclosulam was 341 kg ha^{-1} less than that of the non-treated control group. Both cultivation treatments and both black oat companion crops yielded higher (>140 kg ha^{-1}) than the control. 2,4-DB had a mean grain yield of 783 kg ha^{-1}, which is almost 230 kg ha^{-1} more than that of the non-treated control. In 2008, none of the PRE, with the exception of diclosulam, and POST herbicides and the organic treatments yielded significantly higher than the non-treated control. With a mean grain yield of 548 kg ha^{-1} plots in which diclosulam yielded lowest. Highest yields were obtained in plots treated with 2,4-DB (1580 kg ha^{-1}), fluazifop (1573 kg ha^{-1}) and the lowest rate of pendimethalin (1522 kg ha^{-1}).

Experiments conducted by Payne et al. (2004) in the Pacific Northwest showed a maximum white lupin yield of 2128 kg ha^{-1}, but this yield is not stable. Yield within each cultivar varied greatly between years and depending on the treatment. It is obvious that the grain-type cultivar ABL 1082 had the highest mean grain yield followed by the forage-type cultivar AU Alpha, which is followed by the cover crop-type cultivar AU Homer. Based on the results of this experiment diclosulam, thifensulfuron, chlorimuron and glyphosate caused major grain yield losses. Taylor-Lovell et al. (2001) reported that stand count reductions were more closely related to yield loss than other parameters such as crop injury. However this experiment in white lupin suggests that crop injury was predominately responsible for these yield reductions. Glyphosate did not reduce crop density significantly, but was responsible for severe crop injury and subsequent yield reduction in ABL 1082 and AU Alpha. AU Homer appears to be the least sensitive to herbicide-induced yield reductions, since neither thifensulfuron nor chlorimuron reduced grain yield significantly. Ivany and McCully (1994) stated that POST applications of imazethapyr caused severe crop injury and yield loss in sweet white lupin. Our results did not confirm their findings. Neither the PRE nor the POST imazethpyr applications caused significant crop injury or subsequent yield reduction. Maybe this is due to the use of different cultivars in this study than those used by Ivany and McCully (1994) or the climate and soil differences. The cultivation treatments, between row and between-within row (hoeing) yielded as high as or higher than the non-treated control. Mean grain yield of cultivars in which these treatments were used was slightly higher than that of plots treated with linuron or metribuzin. This coincides with observations made by Sandhu et al. (1991) in lentil. This may be a result of the reduced crop injury by these treatments.

It is essential to continue the further investigation of the most promising weed control practices of this experiment, i.e. imazethapyr, pendimethalin, 2,4-DB, the grass active herbicides and organic treatments to ensure the consistency of low crop injury levels and high yields in white lupin production. Only an ongoing investigation of the promising herbicides can lead to registration of some of these active ingredients for use in white lupin.

Mean test weight

The mean test weight in the non-treated controls of ABL 1082, AU Alpha and AU Homer were 80, 77 and 76 kg $100L^{-1}$, respectively. Mean test weight was not influenced significantly by any treatment at the significance level of $\alpha = 0.1$ (Table 3.16). In 2008, the only exception was diclosulam, which had a significantly lower test weight (77.94 kg $100L^{-1}$) than the non-treated control of white lupin cultivar ABL 1082.

Seed mass

Mean seed mass (mg $seed^{-1}$) of the three cultivars was lower in 2007 than in 2008. In 2007, the non-treated controls had a mean seed mass of 199.94 mg $seed^{-1}$ (ABL 1082), 212 mg seed $^{-1}$ (AU Alpha) and 217.98 mg $seed^{-1}$. In 2008, the non-treated controls of ABL 1082, AU Alpha and AU Homer had a mean seed mass of 230 mg $seed^{-1}$, 255 mg $seed^{-1}$ and 254 mg $seed^{-1}$, respectively. Mean seed mass was not influenced significantly by the treatments over the course of this study at the significance level of $\alpha = 0.1$ (Table 3.17). The only exception was diclosulam in cultivar AU Homer in 2007, which had a significantly lower mean seed mass (177 mg $seed^{-1}$) than the non-treated control.

The test weights and seed mass within each cultivar varied little. Even among the cultivars theses values were similar to each other. This indicates in my opinion that grain yield is primarily influence by the amount of seed produced than by seed size.

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Table 3.01: Mean crop injury of *L. albus* cultivar ABL 1082 on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the first rating 3 and 4 weeks after PRE at FCU and PBU in 2007 and 2008, respectively.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P*-*value*	Mean crop injury	95% CI	Dunnett's *P*-*value*
2007	1	None	Control	0.69	(0.34, 1.15)		0.22	(0.05, 0.52)	
	2	S-metolachlor/Linuron	PRE	0.75	(0.09, 1.94)	1.0000	1.29	(0.35, 2.71)	0.2063
	3	Metribuzin	PRE	0.06	(0.10, 0.66)	0.4390	0.75	(0.09, 1.94)	0.9088
	4	Linuron	PRE	1.22	(0.31, 2.62)	0.9934	2.76	(1.33, 4.48)	0.0001
	5	S-metolachlor	PRE	0.75	(0.09, 1.94)	1.0000	0.57	(0.04, 1.67)	0.9940
	6	Pendimethalin (0.5x)	PRE	0.50	(0.02, 1.55)	1.0000	0.75	(0.09, 1.94)	0.9088
	7	Pendimethalin (1x)	PRE	0.06	(0.10, 0.66)	0.4390	1.22	(0.31, 2.62)	0.2684
	8	Pendimethalin (2x)	PRE	1.68	(0.57, 3.20)	0.6956	0.57	(0.04, 1.67)	0.9940
	9	Diclosulam	PRE	0.57	(0.04, 1.67)	1.0000	0.91	(0.16, 2.18)	0.7044
	10	Flumioxazin	PRE	1.72	(0.60, 3.26)	0.6372	1.22	(0.31, 2.62)	0.2684
	11	Imazethapyr	PRE	1.22	(0.31, 2.62)	0.9934	1.22	(0.31, 2.62)	0.2684
	12	Thifensulfuron	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Chloriumron	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.57	(0.04, 1.67)	1.0000	0.26	(0.00, 1.12)	1.0000
	22	Between-within row	Organic	0.26	(0.00, 1.12)	0.9793	0.06	(0.10, 0.66)	0.9996
	23	SoilSaver Black Oat	Organic	0.38	(0.00, 1.35)	0.9997	0.13	(0.04, 0.85)	1.0000
	24	As_033 Black Oat	Organic	0.57	(0.04, 1.67)	1.0000	0.38	(0.00, 1.35)	1.0000
2008	1	None	Control	0.19	(0.09, 0.32)		0.00	(0.01, 0.03)	
	2	S-metolachlor/Linuron	PRE	1.22	(0.51, 2.18)	0.0174	1.22	(0.51, 2.18)	<0.0001
	3	Metribuzin	PRE	1.00	(0.37, 1.89)	0.0889	1.22	(0.51, 2.18)	<0.0001
	4	Linuron	PRE	0.57	(0.13, 1.31)	0.8336	1.00	(0.37, 1.89)	0.0001
	5	S-metolachlor	PRE	0.57	(0.13, 1.31)	0.8336	0.26	(0.01, 0.81)	0.2918
	6	Pendimethalin (0.5x)	PRE	0.57	(0.13, 1.31)	0.8336	0.06	(0.02, 0.43)	0.9898
	7	Pendimethalin (1x)	PRE	0.26	(0.01, 0.81)	1.0000	0.57	(0.13, 1.31)	0.0091
	8	Pendimethalin (2x)	PRE	0.75	(0.22, 1.55)	0.4245	1.00	(0.37, 1.89)	0.0001
	9	Diclosulam	PRE	1.22	(0.51, 2.18)	0.0174	0.57	(0.13, 1.31)	0.0091
	10	Flumioxazin	PRE	0.26	(0.01, 0.81)	1.0000	2.48	(1.47, 3.66)	<0.0001
	11	Imazethapyr	PRE	0.57	(0.13, 1.31)	0.8336	0.57	(0.13, 1.31)	0.0091
	12	Carfentrazone	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Plant oil	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.00	(0.16, 0.16)	0.4627	0.00	(0.16, 0.16)	1.0000
	22	Between-within row	Organic	0.06	(0.02, 0.43)	0.9992	0.00	(0.16, 0.16)	1.0000
	23	SoilSaver Black Oat	Organic	0.06	(0.02, 0.43)	0.9992	0.00	(0.16, 0.16)	1.0000
	24	As_033 Black Oat	Organic	0.57	(0.13, 1.31)	0.8336	0.00	(0.16, 0.16)	1.0000

Table 3.02: Mean crop injury of *L. albus* cultivar ABL 1082 on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the second rating (12 weeks after PRE) at FCU and PBU in 2008 only.

Treatment			FCU			PBU		
No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
1	None	Control	0.16	(0.06, 0.31)		0.08	(0.02, 0.20)	
2	S-metolachlor/Linuron	PRE	1.00	(0.30, 2.05)	0.1683	1.46	(0.58, 2.65)	0.0019
3	Metribuzin	PRE	1.72	(0.76, 2.97)	0.0020	0.57	(0.09, 1.44)	0.5428
4	Linuron	PRE	0.06	(0.05, 0.51)	1.0000	0.26	(0.00, 0.93)	0.9983
5	S-metolachlor	PRE	1.12	(0.37, 2.21)	0.0864	0.13	(0.01, 0.68)	1.0000
6	Pendimethalin (0.5x)	PRE	0.26	(0.00, 0.93)	1.0000	1.00	(0.30, 2.05)	0.0468
7	Pendimethalin (1x)	PRE	0.75	(0.16, 1.70)	0.5454	0.26	(0.00, 0.93)	0.9983
8	Pendimethalin (2x)	PRE	0.38	(0.02, 1.14)	0.9983	0.26	(0.00, 0.93)	0.9983
9	Diclosulam	PRE	5.00	(3.54, 6.46)	<0.0001	1.35	(0.51, 2.51)	0.0042
10	Flumioxazin	PRE	0.75	(0.16, 1.70)	0.5454	2.62	(1.44, 4.01)	<0.0001
11	Imazethapyr	PRE	0.94	(0.27, 1.98)	0.2257	1.68	(0.73, 2.91)	0.0004
12	Carfentrazone	POST	N/A			N/A		
13	Fluazifop	POST	N/A			N/A		
14	Fomesafen	POST	N/A			N/A		
15	2,4-DB	POST	N/A			N/A		
16	Plant oil	POST	N/A			N/A		
17	Glyphosate	POST	N/A			N/A		
18	Sethoxydim	POST	N/A			N/A		
19	Flumioxazin	POST	N/A			N/A		
20	Imazethapyr	POST	N/A			N/A		
21	Between row cultivation	Organic	0.00	(0.22, 0.22)	0.7820	0.26	(0.00, 0.93)	0.9983
22	Between-within row	Organic	0.21	(0.00, 0.84)	1.0000	0.00	(0.22, 0.22)	0.9781
23	SoilSaver Black Oat	Organic	0.06	(0.05, 0.51)	1.0000	0.06	(0.05, 0.51)	1.0000
24	As_033 Black Oat	Organic	0.38	(0.02, 1.14)	0.9983	0.00	(0.22, 0.22)	0.9781

Table 3.03: Mean crop injury of *L. albus* cultivar ABL 1082 on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the third rating (2 weeks after POST) at FCU and PBU in 2007 and 2008.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
2007	1	None	Control	1.49	(0.31, 3.34)		0.91	(0.07, 2.52)	
	2	S-metolachlor/Linuron	PRE	0.38	(0.01, 1.64)	0.8758	2.16	(0.68, 4.19)	0.9490
	3	Metribuzin	PRE	1.85	(0.49, 3.80)	1.0000	1.95	(0.55, 3.93)	0.9891
	4	Linuron	PRE	0.88	(0.07, 2.49)	1.0000	2.40	(0.83, 4.47)	0.8482
	5	S-metolachlor	PRE	2.05	(0.61, 4.05)	1.0000	1.22	(0.19, 2.98)	1.0000
	6	Pendimethalin (0.5x)	PRE	2.32	(0.77, 4.37)	0.9999	1.22	(0.19, 2.98)	1.0000
	7	Pendimethalin (1x)	PRE	1.99	(0.58, 3.98)	1.0000	0.53	(0.00, 1.91)	1.0000
	8	Pendimethalin (2x)	PRE	2.88	(1.15, 5.01)	0.9652	1.46	(0.29, 3.31)	1.0000
	9	Diclosulam	PRE	9.06	(7.42, 9.92)	<0.0001	6.05	(3.86, 8.03)	0.0011
	10	Flumioxazin	PRE	1.56	(0.34, 3.43)	1.0000	0.26	(0.04, 1.38)	0.9934
	11	Imazethapyr	PRE	1.65	(0.39, 3.55)	1.0000	1.46	(0.29, 3.31)	1.0000
	12	Thifensulfuron	POST	10.00	(9.52, 9.52)	<0.0001	10.00	(9.52, 9.52)	<0.0001
	13	Fluazifop	POST	3.81	(1.86, 6.00)	0.5138	1.68	(0.40, 3.58)	0.9997
	14	Fomesafen	POST	8.00	(6.01, 9.42)	<0.0001	2.40	(0.83, 4.47)	0.8482
	15	2,4-DB	POST	0.50	(0.00, 1.86)	0.9631	0.75	(0.03, 2.27)	1.0000
	16	Chloriumron	POST	9.94	(9.12, 9.81)	<0.0001	9.94	(9.12, 9.81)	<0.0001
	17	Glyphosate	POST	6.30	(4.12, 8.24)	0.0060	2.71	(1.04, 4.83)	0.6636
	18	Sethoxydim	POST	2.28	(0.75, 4.33)	1.0000	3.81	(1.86, 6.00)	0.1551
	19	Flumioxazin	POST	7.29	(5.17, 8.96)	0.0003	4.50	(2.43, 6.67)	0.0452
	20	Imazethapyr	POST	4.45	(2.38, 6.62)	0.2304	0.94	(0.08, 2.58)	1.0000
	21	Between row cultivation	Organic	0.62	(0.01, 2.07)	0.9934	0.94	(0.08, 2.58)	1.0000
	22	Between-within row	Organic	3.33	(1.48, 5.50)	0.7900	1.46	(0.29, 3.31)	1.0000
	23	SoilSaver Black Oat	Organic	3.70	(1.76, 5.88)	0.5802	0.50	(0.00, 1.86)	1.0000
	24	As_033 Black Oat	Organic	0.62	(0.01, 2.07)	0.9934	0.26	(0.04, 1.38)	0.9934
2008	1	None	Control	0.75	(0.16, 1.72)		1.72	(0.75, 3.00)	
	2	S-metolachlor/Linuron	PRE	1.00	(0.29, 2.08)	1.0000	3.09	(1.80, 4.55)	0.8164
	3	Metribuzin	PRE	2.40	(1.25, 3.80)	0.3071	1.72	(0.75, 3.00)	1.0000
	4	Linuron	PRE	0.26	(0.00, 0.94)	0.9871	1.22	(0.42, 2.37)	1.0000
	5	S-metolachlor	PRE	1.88	(0.85, 3.18)	0.7463	1.22	(0.42, 2.37)	1.0000
	6	Pendimethalin (0.5x)	PRE	0.53	(0.06, 1.40)	1.0000	0.94	(0.26, 2.00)	0.9871
	7	Pendimethalin (1x)	PRE	0.53	(0.06, 1.40)	1.0000	1.72	(0.75, 3.00)	1.0000
	8	Pendimethalin (2x)	PRE	0.91	(0.24, 1.95)	1.0000	2.11	(1.02, 3.46)	1.0000
	9	Diclosulam	PRE	8.78	(7.63, 9.58)	<0.0001	5.26	(3.76, 6.74)	0.0080
	10	Flumioxazin	PRE	0.75	(0.16, 1.72)	1.0000	6.28	(4.78, 7,66)	0.0002
	11	Imazethapyr	PRE	0.57	(0.08, 1.46)	1.0000	2.51	(1.33, 3.92)	0.9986
	12	Carfentrazone	POST	0.94	(0.26, 2.00)	1.0000	1.22	(0.42, 2.37)	1.0000
	13	Fluazifop	POST	1.72	(0.75, 3.00)	0.8730	1.46	(0.57, 2.68)	1.0000
	14	Fomesafen	POST	2.66	(1.45, 4.08)	0.1776	3.22	(1.91, 4.69)	0.7188
	15	2,4-DB	POST	1.00	(0.29, 2.08)	1.0000	2.40	(1.25, 3.80)	0.9998
	16	Plant oil	POST	0.57	(0.08, 1.46)	1.0000	2.40	(1.25, 3.80)	0.9998
	17	Glyphosate	POST	6.01	(4.50, 7.43)	<0.0001	6.26	(4.75, 7.64)	0.0002
	18	Sethoxydim	POST	1.42	(0.54, 2.62)	0.9932	0.75	(0.16, 1.72)	0.8730
	19	Flumioxazin	POST	1.22	(0.42, 2.37)	0.9999	1.22	(0.42, 2.37)	1.0000
	20	Imazethapyr	POST	1.22	(0.42, 2.37)	0.9999	0.75	(0.16, 1.72)	0.8730
	21	Between row cultivation	Organic	0.00	(0.23, 0.23)	0.1377	1.00	(0.29, 2.08)	0.9951
	22	Between-within row	Organic	0.26	(0.00, 0.94)	0.9871	0.26	(0.00, 0.94)	0.1682
	23	SoilSaver Black Oat	Organic	0.57	(0.08, 1.46)	1.0000	0.75	(0.16, 1.72)	0.8730
	24	As_033 Black Oat	Organic	0.75	(0.16, 1.72)	1.0000	0.26	(0.00, 0.94)	0.1682

Table 3.04: Mean crop injury of *L. albus* cultivar AU Alpha on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the first rating 3 and 4 weeks after PRE at FCU and PBU in 2007 and 2008, respectively.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P*-*value*	Mean crop injury	95% CI	Dunnett's *P*-*value*
2007	1	None	Control	0.45	(0.18, 0.85)		0.24	(0.06, 0.55)	
	2	S-metolachlor/Linuron	PRE	0.57	(0.04, 1.67)	1.0000	2.46	(1.11, 4.14)	0.0010
	3	Metribuzin	PRE	1.39	(0.41, 2.84)	0.5972	1.61	(0.53, 3.12)	0.0630
	4	Linuron	PRE	0.57	(0.04, 1.67)	1.0000	1.00	(0.20, 2.31)	0.6064
	5	S-metolachlor	PRE	0.75	(0.09, 1.94)	0.9999	1.95	(0.75, 3.54)	0.0128
	6	Pendimethalin (0.5x)	PRE	0.26	(0.00, 1.12)	1.0000	1.68	(0.57, 3.20)	0.0463
	7	Pendimethalin (1x)	PRE	0.75	(0.09, 1.94)	0.9999	1.68	(0.57, 3.20)	0.0463
	8	Pendimethalin (2x)	PRE	0.53	(0.03, 1.60)	1.0000	1.46	(0.45, 2.93)	0.1173
	9	Diclosulam	PRE	1.00	(0.20, 2.31)	0.9749	1.46	(0.45, 2.93)	0.1173
	10	Flumioxazin	PRE	0.91	(0.16, 2.18)	0.9942	2.40	(1.07, 4.07)	0.0013
	11	Imazethapyr	PRE	0.57	(0.04, 1.67)	1.0000	0.94	(0.17, 2.23)	0.6926
	12	Thifensulfuron	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Chloriumron	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.38	(0.00, 1.35)	1.0000	0.38	(0.00, 1.35)	1.0000
	22	Between-within row	Organic	1.12	(0.26, 2.48)	0.9101	1.00	(0.20, 2.31)	0.6064
	23	SoilSaver Black Oat	Organic	0.57	(0.04, 1.67)	1.0000	0.06	(0.10, 0.66)	0.9992
	24	As_033 Black Oat	Organic	0.75	(0.09, 1.94)	0.9999	0.91	(0.16, 2.18)	0.7483
2008	1	None	Control	0.15	(0.06, .28)		0.02	(0.00, 0.07)	
	2	S-metolachlor/Linuron	PRE	1.00	(0.37, 1.89)	0.0517	0.57	(0.13, 1.31)	0.0441
	3	Metribuzin	PRE	1.00	(0.37, 1.89)	0.0517	1.00	(0.37, 1.89)	0.0006
	4	Linuron	PRE	0.57	(0.13, 1.31)	0.7007	0.06	(0.02, 0.43)	1.0000
	5	S-metolachlor	PRE	0.26	(0.01, 0.81)	1.0000	0.57	(0.13, 1.31)	0.0441
	6	Pendimethalin (0.5x)	PRE	0.57	(0,13, 1.31)	0.7007	0.06	(0.02, 0.43)	1.0000
	7	Pendimethalin (1x)	PRE	0.00	(0.16, 0.16)	0.6153	0.06	(0.02, 0.43)	1.0000
	8	Pendimethalin (2x)	PRE	0.00	(0.16, 0.16)	0.6153	0.26	(0.01, 0.81)	0.6585
	9	Diclosulam	PRE	1.46	(0.68, 2.48)	0.0013	1.46	(0.68, 2.48)	<0.0001
	10	Flumioxazin	PRE	0.26	(0.01, 0.81)	1.0000	2.24	(1.27, 3.39)	<0.0001
	11	Imazethapyr	PRE	0.75	(0.22, 1.55)	0.2941	1.00	(0.37, 1.89)	0.0006
	12	Carfentrazone	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Plant oil	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.00	(0.16, 0.16)	0.6153	0.00	(0.16, 0.16)	1.0000
	22	Between-within row	Organic	0.00	(0.16, 0.16)	0.6153	0.00	(0.16, 0.16)	1.0000
	23	SoilSaver Black Oat	Organic	0.06	(0.02, 0.43)	1.0000	0.00	(0.16, 0.16)	1.0000
	24	As_033 Black Oat	Organic	0.26	(0.01, 0.81)	1.0000	0.00	(0.16, 0.16)	1.0000

Table 3.05: Mean crop injury of *L. albus* cultivar AU Alpha on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the second rating (12 weeks after PRE) at FCU and PBU in 2008 only.

Treatment			FCU			PBU		
No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
1	None	Control	0.02	(0.00, 0.08)		0.04	(0.00, 0.13)	
2	S-metolachlor/Linuron	PRE	0.57	(0.09, 1.44)	0.1376	0.26	(0.00, 0.93)	0.9646
3	Metribuzin	PRE	0.26	(0.00, 0.93)	0.8343	0.57	(0.09, 1.44)	0.2880
4	Linuron	PRE	0.00	(0.22, 0.22)	1.0000	0.06	(0.05, 0.51)	1.0000
5	S-metolachlor	PRE	0.57	(0.09, 1.44)	0.1376	0.57	(0.99, 1.44)	0.2880
6	Pendimethalin (0.5x)	PRE	0.06	(0.05, 0.51)	1.0000	0.00	(0.22, 0.22)	0.9993
7	Pendimethalin (1x)	PRE	0.00	(0.22, 0.22)	1.0000	0.00	(0.22, 0.22)	0.9993
8	Pendimethalin (2x)	PRE	0.00	(0.22, 0.22)	1.0000	0.06	(0.05, 0.51)	1.0000
9	Diclosulam	PRE	3.73	(2.37, 5.20)	<0.0001	2.74	(1.53, 4.14)	<0.0001
10	Flumioxazin	PRE	0.26	(0.00, 0.93)	0.8343	1.72	(0.76, 2.97)	0.0001
11	Imazethapyr	PRE	0.26	(0.00, 0.93)	0.8343	1.72	(0.76, 2.97)	0.0001
12	Carfentrazone	POST	N/A			N/A		
13	Fluazifop	POST	N/A			N/A		
14	Fomesafen	POST	N/A			N/A		
15	2,4-DB	POST	N/A			N/A		
16	Plant oil	POST	N/A			N/A		
17	Glyphosate	POST	N/A			N/A		
18	Sethoxydim	POST	N/A			N/A		
19	Flumioxazin	POST	N/A			N/A		
20	Imazethapyr	POST	N/A			N/A		
21	Between row cultivation	Organic	0.00	(0.22, 0.22)	1.0000	0.00	(0.22, 0.22)	0.9993
22	Between-within row	Organic	0.06	(0.05, 0.51)	1.0000	0.00	(0.22, 0.22)	0.9993
23	SoilSaver Black Oat	Organic	0.00	(0.22, 0.22)	1.0000	0.00	(0.22, 0.22)	0.9993
24	As_033 Black Oat	Organic	0.06	(0.05, 0.51)	1.0000	0.00	(0.22, 0.22)	0.9993

Table 3.06: Mean crop injury of *L. albus* cultivar AU Alpha on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the third rating (2 weeks after POST) at FCU and PBU in 2007 and 2008.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
2007	1	None	Control	0.21	(0.06, 1.27)		1.68	(0.40, 3.58)	
	2	S-metolachlor/Linuron	PRE	1.68	(0.40, 3.58)	0.4758	1.22	(0.19, 2.98)	1.0000
	3	Metribuzin	PRE	4.45	(2.38, 6.62)	0.0011	1.68	(0.40, 3.58)	1.0000
	4	Linuron	PRE	0.75	(0.03, 2.27)	0.9980	0.91	(0.07, 2.52)	0.9997
	5	S-metolachlor	PRE	1.04	(0.12, 2.72)	0.9355	1.95	(0.55, 3.93)	1.0000
	6	Pendimethalin (0.5x)	PRE	0.38	(0.01, 1.64)	1.0000	1.72	(0.43, 3.65)	1.0000
	7	Pendimethalin (1x)	PRE	0.57	(0.00, 1.98)	1.0000	1.46	(0.29, 3.31)	1.0000
	8	Pendimethalin (2x)	PRE	3.95	(1.97, 6.14)	0.0042	1.22	(0.19, 2.98)	1.0000
	9	Diclosulam	PRE	9.94	(9.12, 9.81)	<0.0001	4.74	(2.63, 6.89)	0.2180
	10	Flumioxazin	PRE	2.86	(1.14, 4.99)	0.0555	1.00	(0.10, 2.66)	1.0000
	11	Imazethapyr	PRE	2.08	(0.63, 4.08)	0.2500	1.35	(0.24, 3.16)	1.0000
	12	Thifensulfuron	POST	9.52	(8.17, 10.00)	<0.0001	9.87	(8.91, 9.89)	<0.0001
	13	Fluazifop	POST	0.50	(0.00, 1.86)	1.0000	2.62	(0.97, 4.72)	0.9997
	14	Fomesafen	POST	6.78	(4.62, 8.60)	<0.0001	3.36	(1.50, 5.53)	0.8909
	15	2,4-DB	POST	0.57	(0.00, 1.98)	1.0000	0.75	(0.03, 2.27)	0.9934
	16	Chloriumron	POST	9.99	(9.53, 9.23)	<0.0001	9.62	(8.36, 9.99)	<0.0001
	17	Glyphosate	POST	5.89	(3.71, 7.90)	<0.0001	1.42	(0.27, 3.25)	1.0000
	18	Sethoxydim	POST	0.26	(0.04, 1.38)	1.0000	1.22	(0.19, 2.98)	1.0000
	19	Flumioxazin	POST	7.84	(5.81, 9.32)	<0.0001	3.70	(1.76, 5.88)	0.7209
	20	Imazethapyr	POST	1.06	(0.12, 2.75)	0.9242	1.46	(0.29, 3.31)	1.0000
	21	Between row cultivation	Organic	0.29	(0.02, 1.45)	1.0000	1.22	(0.19, 2.98)	1.0000
	22	Between-within row	Organic	1.58	(0.35, 3.46)	0.5455	1.72	(0.43, 3.65)	1.0000
	23	SoilSaver Black Oat	Organic	0.26	(0.04, 1.38)	1.0000	1.35	(0.24, 3.16)	1.0000
	24	As_033 Black Oat	Organic	0.75	(0.03, 2.27)	0.9980	0.88	(0.07, 2.49)	0.9995
2008	1	None	Control	0.57	(0.08, 1.46)		1.00	(0.29, 2.08)	
	2	S-metolachlor/Linuron	PRE	0.57	(0.08, 1.46)	1.0000	0.57	(0.08, 1.46)	0.9999
	3	Metribuzin	PRE	0.26	(0.00, 0.94)	0.9999	0.57	(0.08, 1.46)	0.9999
	4	Linuron	PRE	0.06	(0.05, 0.53)	0.8164	0.57	(0.08, 1.46)	0.9999
	5	S-metolachlor	PRE	1.22	(0.42, 2.37)	0.9871	0.06	(0.05, 0.53)	0.2778
	6	Pendimethalin (0.5x)	PRE	0.38	(0.02, 1.16)	1.0000	0.57	(0.08, 1.46)	0.9999
	7	Pendimethalin (1x)	PRE	1.06	(0.32, 2,16)	0.9994	0.38	(0,02, 1.16)	0.9716
	8	Pendimethalin (2x)	PRE	0.57	(0.08, 1.46)	1.0000	1.00	(0.29, 2.08)	1.0000
	9	Diclosulam	PRE	9.00	(7.92, 9.71)	<0.0001	9.00	(7.92, 9.71)	<0.0001
	10	Flumioxazin	PRE	0.57	(0.08, 1.46)	1.0000	2.51	(1.33, 3.92)	0.5138
	11	Imazethapyr	PRE	0.26	(0.00, 0.94)	0.9999	1.22	(0.42, 2.37)	1.0000
	12	Carfentrazone	POST	1.46	(0.57, 2.68)	0.8730	0.57	(0.08, 1.46)	0.9999
	13	Fluazifop	POST	1.46	(0.57, 2.68)	0.8730	1.22	(0.42, 2.37)	1.0000
	14	Fomesafen	POST	3.22	(1.91, 4.69)	0.0155	3.48	(2.13, 4.97)	0.0648
	15	2,4-DB	POST	0.38	(0.02, 1.16)	1.0000	0.26	(0.00, 0.94)	0.8164
	16	Plant oil	POST	0.06	(0.05, 0.53)	0.8164	1.00	(0.29, 2.08)	1.0000
	17	Glyphosate	POST	4.49	(3.03, 5.99)	0.0001	5.25	(3.75, 6.73)	0.0002
	18	Sethoxydim	POST	1.00	(0.29, 2.08)	0.9999	1.00	(0.29, 2.08)	1.0000
	19	Flumioxazin	POST	0.38	(0.02, 1.16)	1.0000	1.22	(0.42, 2.37)	1.0000
	20	Imazethapyr	POST	0.06	(0.05, 0.53)	0.8164	0.38	(0.02, 1.16)	0.9716
	21	Between row cultivation	Organic	0.57	(0.08, 1.46)	1.0000	1.00	(0.29, 2.08)	1.0000
	22	Between-within row	Organic	0.57	(0.08, 1.46)	1.0000	0.57	(0.08, 1.46)	0.9999
	23	SoilSaver Black Oat	Organic	0.06	(0.05. 0.53)	0.8164	1.00	(0.29, 2.08)	1.0000
	24	As_033 Black Oat	Organic	0.00	(0.23, 0.23)	0.2778	1.00	(0.29, 2.08)	1.0000

Table 3.07: Mean crop injury of *L. albus* cultivar AU Homer on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the first rating 3 and 4 weeks after PRE at FCU and PBU in 2007 and 2008, respectively.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
2007	1	None	Control	0.21	(0.04, 0.49)		0.25	(0.06, 0.56)	
	2	S-metolachlor/Linuron	PRE	0.26	(0.00, 1.12)	1.0000	1.46	(0.45, 2.93)	0.1317
	3	Metribuzin	PRE	0.75	(0.09, 1.94)	0.8739	1.22	(0.31, 2.62)	0.3324
	4	Linuron	PRE	0.57	(0.04, 1.67)	0.9887	0.75	(0.09, 1.94)	0.9464
	5	S-metolachlor	PRE	0.94	(0.17, 2.23)	0.5870	0.57	(0.04, 1.67)	0.9979
	6	Pendimethalin (0.5x)	PRE	1.22	(0.31, 2.62)	0.2282	0.06	(0.10, 0.66)	0.9986
	7	Pendimethalin (1x)	PRE	1.22	(0.31, 2.62)	0.2282	1.00	(0.20, 2.31)	0.6425
	8	Pendimethalin (2x)	PRE	0.75	(0.09, 1.94)	0.8739	0.38	(0.00, 1.35)	1.0000
	9	Diclosulam	PRE	0.91	(0.16, 2.18)	0.6466	1.00	(0.20, 2.31)	0.6425
	10	Flumioxazin	PRE	2.48	(1.12, 4.16)	0.0005	1.46	(0.45, 2.93)	0.1317
	11	Imazethapyr	PRE	0.38	(0.00, 1.35)	1.0000	0.62	(0.05, 1.75)	0.9932
	12	Thifensulfuron	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Chloriumron	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.06	(010, 0.66)	0.9999	0.91	(0.16, 2.18)	0.7802
	22	Between-within row	Organic	0.00	(0.32, 0.32)	0.8001	0.06	(0.10, 0.66)	0.9986
	23	SoilSaver Black Oat	Organic	0.06	(0.10, 0.66)	0.9999	0.26	(0.00, 1.12)	1.0000
	24	As_033 Black Oat	Organic	0.57	(0.04, 1.67)	0.9887	0.06	(0.10, 0.66)	0.9986
2008	1	None	Control	0.55	(0.37, 0.77)		0.02	(0,00, 007)	
	2	S-metolachlor/Linuron	PRE	0.57	(0.13, 1.31)	1.0000	0.26	(0.01, 0.81)	0.6585
	3	Metribuzin	PRE	1.68	(0.84, 2.73)	0.0894	0.75	(0.22, 1.55)	0.0076
	4	Linuron	PRE	0.57	(0.13, 1.31)	1.0000	0.26	(0.01, 0.81)	0.6585
	5	S-metolachlor	PRE	1.42	(0.65, 2.42)	0.3246	1.00	(0.37, 1.89)	0.0006
	6	Pendimethalin (0.5x)	PRE	0.06	(0.02, 0.43)	0.2602	0.57	(0.13, 1.31)	0.0441
	7	Pendimethalin (1x)	PRE	0.26	(0.01, 0.81)	0.9842	0.06	(0.02, 0.43)	1.0000
	8	Pendimethalin (2x)	PRE	0.53	(0.11, 1.24)	1.0000	0.26	(0.01, 0.81)	0.6585
	9	Diclosulam	PRE	1.22	(0.51, 2.18)	0.6615	0.57	(0.13, 1.31)	0.0441
	10	Flumioxazin	PRE	0.75	(0.22, 1.55)	1.0000	1.72	(0.87, 2.79)	<0.0001
	11	Imazethapyr	PRE	0.00	(0.16, 0.16)	0.0075	1.00	(0.37, 1.89)	0.0006
	12	Carfentrazone	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Plant oil	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	0.13	(0.00, 0.59)	0.6555	0.00	(0.16, 0,16)	1.0000
	22	Between-within row	Organic	0.06	(0.02, 0.43)	0.2602	0.00	(0.16, 0,16)	1.0000
	23	SoilSaver Black Oat	Organic	0.26	(0.01, 0.81)	0.9842	0.00	(0.16, 0,16)	1.0000
	24	As_033 Black Oat	Organic	0.00	(0.16, 0.16)	0.0075	0.00	(0.16, 0,16)	1.0000

Table 3.08: Mean crop injury of *L. albus* cultivar AU Homer on a scale from 0 (no injury/ alive) to 10 (complete injury) at the second rating (12 weeks after PRE) at FCU and PBU in 2008 only.

Treatment			FCU			PBU		
No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
1	None	Control	0.43	(0.25, 0.66)		0.04	(0.00, 0.13)	
2	S-metolachlor/Linuron	PRE	1.12	(0.37, 2.21)	0.7323	0.26	(0.00, 0.93)	0.9646
3	Metribuzin	PRE	0.91	(0.25, 1.92)	0.9644	0.75	(0.16, 1.70)	0.0929
4	Linuron	PRE	0.06	(0.05, 0.51)	0.7641	0.06	(0.05, 0.51)	1.0000
5	S-metolachlor	PRE	1.42	(0.55, 2.60)	0.2875	1.22	(0.43, 2.35)	0.0030
6	Pendimethalin (0.5x)	PRE	0.57	(0.09, 1.44)	1.0000	0.26	(0.00, 0.93)	0.9646
7	Pendimethalin (1x)	PRE	0.26	(0.00, 0.93)	1.0000	0.00	(0.22, 0.22)	0.9993
8	Pendimethalin (2x)	PRE	0.57	(0.09, 1.44)	1.0000	0.57	(0.09, 1.44)	0.2880
9	Diclosulam	PRE	4.75	(3.30, 6.22)	<0.0001	1.72	(0.76, 2.97)	0.0001
10	Flumioxazin	PRE	0.38	(0.02, 1.14)	1.0000	1.22	(0.43, 2.35)	0.0030
11	Imazethapyr	PRE	1.22	(0.43, 2.35)	0.5662	1.00	(0.30, 2.05)	0.0155
12	Carfentrazone	POST	N/A			N/A		
13	Fluazifop	POST	N/A			N/A		
14	Fomesafen	POST	N/A			N/A		
15	2,4-DB	POST	N/A			N/A		
16	Plant oil	POST	N/A			N/A		
17	Glyphosate	POST	N/A			N/A		
18	Sethoxydim	POST	N/A			N/A		
19	Flumioxazin	POST	N/A			N/A		
20	Imazethapyr	POST	N/A			N/A		
21	Between row cultivation	Organic	0.00	(0.22, 0,22)	0.1042	0.00	(0.22, 0.22)	0.9993
22	Between-within row	Organic	0.06	(0.05. 0.51)	0.7641	0.00	(0.22, 0.22)	0.9993
23	SoilSaver Black Oat	Organic	0.06	(0.05. 0.51)	0.7641	0.06	(0.05, 0.51)	1.0000
24	As_033 Black Oat	Organic	0.13	(0.01, 0.68)	0.9733	0.00	(0.22, 0.22)	0.9993

Table 3.09: Mean crop injury of *L. albus* cultivar AU Homer on a scale from 0 (no injury/ alive) to 10 (complete injury/dead) at the third rating (2 weeks after POST) at FCU and PBU in 2007 and 2008.

	Treatment			FCU			PBU		
Year	No	Name	Class	Mean crop injury	95% CI	Dunnett's *P-value*	Mean crop injury	95% CI	Dunnett's *P-value*
2007	1	None	Control	0.57	(0.00, 1.98)		1.06	(0.12, 2.75)	
	2	S-metolachlor/Linuron	PRE	0.26	(0.04, 1.38)	1.0000	0.57	(0.00, 1.98)	1.0000
	3	Metribuzin	PRE	0.06	(0.19, 0.88)	0.9795	1.22	(0.19, 2.98)	1.0000
	4	Linuron	PRE	0.26	(0.04, 1.38)	1.0000	1.00	(0.10, 2.66)	1.0000
	5	S-metolachlor	PRE	1.68	(0.40, 3.58)	0.9422	1.46	(0.29, 3.31)	1.0000
	6	Pendimethalin (0.5x)	PRE	0.26	(0.04, 1.38)	1.0000	0.75	(0.03, 2.27)	1.0000
	7	Pendimethalin (1x)	PRE	1.22	(0.19, 2.98)	0.9997	0.38	(0.01, 1.64)	0.9970
	8	Pendimethalin (2x)	PRE	1.46	(0.29, 3.31)	0.9891	2.00	(0.58, 3.99)	0.9980
	9	Diclosulam	PRE	8.54	(6.69, 9.71)	<0.0001	6.79	(4.63, 8.61)	0.0002
	10	Flumioxazin	PRE	0.13	(0.11, 1.09)	0.9989	0.75	(0.03, 2.27)	1.0000
	11	Imazethapyr	PRE	0.38	(0.01, 1.64)	1.0000	1.68	(0.04, 3.58)	1.0000
	12	Thifensulfuron	POST	10.00	(9.52, 9.52)	<0.0001	9.43	(8.02, 10.00)	<0.0001
	13	Fluazifop	POST	2.71	(1.04, 4.83)	0.3323	1.68	(0.40, 3.58)	1.0000
	14	Fomesafen	POST	7.37	(5.27, 9.02)	<0.0001	2.71	(1.04, 4.83)	0.8047
	15	2,4-DB	POST	0.75	(0.03, 2.27)	1.0000	0.06	(0.19, 0.88)	0.6103
	16	Chloriumron	POST	10.00	(9.52, 9.52)	<0.0001	9.74	(8.62, 9.96)	<0.0001
	17	Glyphosate	POST	2.91	(1.17, 5.04)	0.2497	2.18	(0.69, 4.21)	0.9868
	18	Sethoxydim	POST	1.22	(0.19, 2.98)	0.9997	0.75	(0.03, 2.27)	1.0000
	19	Flumioxazin	POST	6.01	(3.83, 8.00)	0.0002	6.02	(3.84, 8.01)	0.0024
	20	Imazethapyr	POST	1.12	(0.15, 2.83)	1.0000	1.00	(0.10, 2.66)	1.0000
	21	Between row cultivation	Organic	1.22	(0.19, 2.98)	0.9997	0.94	(0.08, 2.58)	1.0000
	22	Between-within row	Organic	0.26	(0.04, 1.38)	1.0000	1.68	(0.40, 3.58)	1.0000
	23	SoilSaver Black Oat	Organic	0.57	(0.00, 1.98)	1.0000	1.00	(0.10, 2.66)	1.0000
	24	As_033 Black Oat	Organic	0.75	(0.03, 2.27)	1.0000	0.75	(0.03, 2.27)	1.0000
2008	1	None	Control	1.90	(0.87, 3.21)		1.46	(0.57, 2.68)	
	2	S-metolachlor/Linuron	PRE	1.95	(0.91, 3.27)	1.0000	1.22	(0.42, 2.37)	1.0000
	3	Metribuzin	PRE	0.53	(0.06, 1.40)	0.4054	1.00	(0.29, 2.08)	1.0000
	4	Linuron	PRE	0.75	(0.16, 1.72)	0.7267	1.46	(0.57, 2.68)	1.0000
	5	S-metolachlor	PRE	1.95	(0.91, 3.27)	1.0000	0.57	(0.08, 1.46)	0.8730
	6	Pendimethalin (0.5x)	PRE	0.06	(0.05, 0.53)	0.0120	1.22	(0.42, 2.37)	1.0000
	7	Pendimethalin (1x)	PRE	0.26	(0.00, 0.94)	0.1031	1.00	(0.29, 2.08)	1.0000
	8	Pendimethalin (2x)	PRE	0.38	(0.02, 1.16)	0.2178	1.00	(0.29, 2.08)	1.0000
	9	Diclosulam	PRE	7.60	(6.20, 8.75)	<0.0001	7.26	(5.83, 8.49)	<0.0001
	10	Flumioxazin	PRE	0.38	(0.02, 1.16)	0.2178	1.68	(0.71, 2.94)	1.0000
	11	Imazethapyr	PRE	1.46	(0.57, 2.68)	1.0000	1.00	(0.29, 2.08)	1.0000
	12	Carfentrazone	POST	1.12	(0.36, 2.24)	0.9932	1.72	(0.75, 3.00)	1.0000
	13	Fluazifop	POST	0.75	(0.16, 1.72)	0.7267	1.22	(0.42, 2.37)	1.0000
	14	Fomesafen	POST	2.11	(1.02, 3.46)	1.0000	4.00	(2.58, 5.51)	0.0981
	15	2,4-DB	POST	0.06	(0.05, 0.53)	0.0120	1.00	(0.29, 2.08)	1.0000
	16	Plant oil	POST	0.75	(0.16, 1.72)	0.7267	1.22	(0.42, 2.37)	1.0000
	17	Glyphosate	POST	3.09	(1.80, 4.55)	0.9334	7.76	(6.39, 8.88)	<0.0001
	18	Sethoxydim	POST	0.75	(0.16, 1.72)	0.7267	1.00	(0.29, 2.08)	1.0000
	19	Flumioxazin	POST	1.72	(0.75, 3.00)	1.0000	1.72	(0.75, 3.00)	1.0000
	20	Imazethapyr	POST	0.94	(0.26, 2.00)	0.9331	1.46	(0.57, 2.68)	1.0000
	21	Between row cultivation	Organic	0.75	(0.16, 1.72)	0.7267	1.00	(0.29, 2.08)	1.0000
	22	Between-within row	Organic	0.57	(0.08, 1.46)	0.4680	1.00	(0.29, 2.08)	1.0000
	23	SoilSaver Black Oat	Organic	0.75	(0.16, 1.72)	0.7267	1.00	(0.29, 2.08)	1.0000
	24	As_033 Black Oat	Organic	0.26	(0.00, 0.94)	0.1031	1.00	(0.29, 2.08)	1.0000

Table 3.10: Plant density of *L. albus* as influenced by treatment 6 and 4 weeks after PRE in 2007 and 2008, respectively.

	Treatment			FCU			PBU		
Year	No	Name	Class	Plant Density	StdErr	Dunnett's *P-value*	Plant Density	StdErr	Dunnett's *P-value*
				plants m-2					
2007	1	None	Control	11.16	0.14		8.88	0.14	
	2	S-metolachlor/Linuron	PRE	11.18	0.34	1.0000	8.54	0.34	0.9933
	3	Metribuzin	PRE	11.12	0.34	1.0000	8.82	0.34	1.0000
	4	Linuron	PRE	11.51	0.34	0.9919	8.76	0.34	1.0000
	5	S-metolachlor	PRE	10.99	0.34	1.0000	9.36	0.34	0.9015
	6	Pendimethalin (0.5x)	PRE	11.02	0.34	1.0000	8.79	0.34	1.0000
	7	Pendimethalin (1x)	PRE	11.02	0.34	1.0000	8.81	0.34	1.0000
	8	Pendimethalin (2x)	PRE	11.17	0.34	1.0000	9.06	0.34	1.0000
	9	Diclosulam	PRE	11.00	0.34	1.0000	8.55	0.34	0.9957
	10	Flumioxazin	PRE	11.62	0.34	0.9295	9.30	0.34	0.9627
	11	Imazethapyr	PRE	11.29	0.34	1.0000	8.72	0.34	1.0000
	12	Thifensulfuron	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Chlorimuron	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	11.05	0.34	1.0000	8.52	0.34	0.9901
	22	Between-within row	Organic	10.99	0.34	1.0000	8.82	0.34	1.0000
	23	SoilSaver Black Oat	Organic	10.93	0.34	0.9999	8.31	0.34	0.7360
	24	As_033 Black Oat	Organic	11.56	0.34	0.9764	8.43	0.34	0.9371
2008	1	None	Control	10.35	0.15		10.97	0.15	
	2	S-metolachlor/Linuron	PRE	10.36	0.36	1.0000	10.76	0.36	1.0000
	3	Metribuzin	PRE	10.41	0.36	1.0000	10.88	0.36	1.0000
	4	Linuron	PRE	10.23	0.36	1.0000	10.52	0.36	0.9779
	5	S-metolachlor	PRE	10.73	0.36	0.9948	10.60	0.36	0.9959
	6	Pendimethalin (0.5x)	PRE	10.60	0.36	1.0000	10.82	0.36	1.0000
	7	Pendimethalin (1x)	PRE	10.09	0.36	0.9999	11.33	0.36	0.9968
	8	Pendimethalin (2x)	PRE	10.45	0.36	1.0000	11.20	0.36	1.0000
	9	Diclosulam	PRE	10.23	0.36	1.0000	11.29	0.36	0.9992
	10	Flumioxazin	PRE	10.26	0.36	1.0000	7.40	0.36	<0.0001
	11	Imazethapyr	PRE	10.44	0.36	1.0000	11.39	0.36	0.9863
	12	Carfentrazone	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Plant oil	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	10.64	0.36	0.9997	11.12	0.36	1.0000
	22	Between-within row	Organic	10.26	0.36	1.0000	11.56	0.36	0.8437
	23	SoilSaver Black Oat	Organic	10.49	0.36	1.0000	11.15	0.36	1.0000
	24	As_033 Black Oat	Organic	9.97	0.36	0.9944	11.45	0.36	0.9588

Table 3.11: Plant density of *L. albus* as influenced by treatment 11 and 8 weeks after PRE in 2007 and 2008, respectively.

	Treatment			FCU			PBU		
Year	No	Name	Class	Plant Density	StdErr	Dunnett's *P-value*	Plant Density	StdErr	Dunnett's *P-value*
				plants m-2					
2007	1	None	Control	10.60	0.34		8.10	0.34	
	2	S-metolachlor/Linuron	PRE	10.36	0.34	1.0000	8.04	0.34	1.0000
	3	Metribuzin	PRE	10.44	0.34	1.0000	8.03	0.34	1.0000
	4	Linuron	PRE	10.48	0.34	1.0000	8.49	0.34	0.9993
	5	S-metolachlor	PRE	10.29	0.34	1.0000	8.43	0.34	0.9999
	6	Pendimethalin (0.5x)	PRE	10.41	0.34	1.0000	8.21	0.34	1.0000
	7	Pendimethalin (1x)	PRE	10.05	0.34	0.9607	8.19	0.34	1.0000
	8	Pendimethalin (2x)	PRE	10.21	0.34	0.9994	8.55	0.34	0.9956
	9	Diclosulam	PRE	10.08	0.34	0.9766	7.79	0.34	1.0000
	10	Flumioxazin	PRE	10.35	0.34	1.0000	8.31	0.34	1.0000
	11	Imazethapyr	PRE	10.23	0.34	0.9996	8.21	0.34	1.0000
	12	Thifensulfuron	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Chlorimuron	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	10.38	0.34	1.0000	7.86	0.34	1.0000
	22	Between-within row	Organic	10.23	0.34	0.9996	8.13	0.34	1.0000
	23	SoilSaver Black Oat	Organic	10.21	0.34	0.9994	7.42	0.34	0.8112
	24	As_033 Black Oat	Organic	10.57	0.34	1.0000	7.92	0.34	1.0000
2008	1	None	Control	9.61	0.36		9.25	0.36	
	2	S-metolachlor/Linuron	PRE	9.58	0.36	1.0000	8.58	0.36	0.9107
	3	Metribuzin	PRE	8.64	0.36	0.4791	8.58	0.36	0.9107
	4	Linuron	PRE	9.24	0.36	0.9999	9.36	0.36	1.0000
	5	S-metolachlor	PRE	9.60	0.36	1.0000	9.72	0.36	0.9980
	6	Pendimethalin (0.5x)	PRE	9.39	0.36	1.0000	9.09	0.36	1.0000
	7	Pendimethalin (1x)	PRE	9.33	0.36	1.0000	9.75	0.36	0.9956
	8	Pendimethalin (2x)	PRE	8.98	0.36	0.9479	9.45	0.36	1.0000
	9	Diclosulam	PRE	7.22	0.36	0.0001	10.17	0.36	0.5707
	10	Flumioxazin	PRE	9.01	0.36	0.9660	4.71	0.36	<0.0001
	11	Imazethapyr	PRE	9.22	0.36	0.9998	9.90	0.36	0.9368
	12	Carfentrazone	POST	N/A			N/A		
	13	Fluazifop	POST	N/A			N/A		
	14	Fomesafen	POST	N/A			N/A		
	15	2,4-DB	POST	N/A			N/A		
	16	Plant oil	POST	N/A			N/A		
	17	Glyphosate	POST	N/A			N/A		
	18	Sethoxydim	POST	N/A			N/A		
	19	Flumioxazin	POST	N/A			N/A		
	20	Imazethapyr	POST	N/A			N/A		
	21	Between row cultivation	Organic	9.84	0.36	1.0000	10.00	0.36	0.8232
	22	Between-within row	Organic	9.54	0.36	1.0000	9.85	0.36	0.9660
	23	SoilSaver Black Oat	Organic	9.52	0.36	1.0000	9.52	0.36	1.0000
	24	As_033 Black Oat	Organic	9.18	0.36	0.9992	9.91	0.36	0.9244

Table 3.12: Plant density in plants m^{-2} of *L. albus* cultivar ABL 1082 as influenced by treatment 3 weeks after POST in 2007 only. Due to heavy rains after POST application in study year 2008 plots were inaccessible.

Treatment			FCU			PBU		
No	Name	Class	Plant Density	StdErr	Dunnett's *P-value*	Plant Density	StdErr	Dunnett's *P-value*
			plants m-2					
1	None	Control	8.84	0.69		9.24	0.69	
2	S-metolachlor/Linuron	PRE	9.60	0.69	0.9997	8.30	0.69	0.9945
3	Metribuzin	PRE	8.93	0.69	1.0000	8.70	0.69	1.0000
4	Linuron	PRE	9.69	0.69	0.9985	7.67	0.69	0.6874
5	S-metolachlor	PRE	8.79	0.69	1.0000	9.46	0.69	1.0000
6	Pendimethalin (0.5x)	PRE	9.82	0.69	0.9906	8.43	0.69	0.9993
7	Pendimethalin (1x)	PRE	9.28	0.69	1.0000	8.25	0.69	0.9906
8	Pendimethalin (2x)	PRE	9.64	0.69	0.9993	8.48	0.69	0.9997
9	Diclosulam	PRE	5.61	0.69	0.0122	8.16	0.69	0.9767
10	Flumioxazin	PRE	7.98	0.69	0.9985	9.06	0.69	1.0000
11	Imazethapyr	PRE	9.01	0.69	1.0000	8.84	0.69	1.0000
12	Thifensulfuron	POST	0.00	0.76	<0.0001	0.04	0.76	<0.0001
13	Fluazifop	POST	8.12	0.69	0.9999	8.61	0.69	1.0000
14	Fomesafen	POST	8.61	0.69	1.0000	7.58	0.69	0.6109
15	2,4-DB	POST	9.42	0.69	1.0000	8.25	0.69	0.9906
16	Chlorimuron	POST	0.00	0.76	<0.0001	0.00	0.76	<0.0001
17	Glyphosate	POST	7.89	0.69	0.9945	8.79	0.69	1.0000
18	Sethoxydim	POST	7.89	0.69	0.9945	8.88	0.69	1.0000
19	Flumioxazin	POST	8.57	0.69	1.0000	8.48	0.69	0.9997
20	Imazethapyr	POST	7.67	0.69	0.9515	8.39	0.69	0.9985
21	Between row cultivation	Organic	10.09	0.69	0.9129	8.66	0.69	1.0000
22	Between-within row	Organic	8.43	0.69	1.0000	8.88	0.69	1.0000
23	SoilSaver Black Oat	Organic	9.10	0.69	1.0000	7.13	0.69	0.2793
24	As_033 Black Oat	Organic	9.60	0.69	0.9997	7.76	0.69	0.7618

Table 3.13: Plant density in plants m^{-2} of *L. albus* cultivar AU Alpha as influenced by treatment 3 weeks after POST in 2007 only. Due to heavy rains after POST application in study year 2008 plots were inaccessible.

Treatment			FCU			PBU		
No	Name	Class	Plant Density	StdErr	Dunnett's *P-value*	Plant Density	StdErr	Dunnett's *P-value*
			plants m-2					
1	None	Control	11.12	0.69		5.56	0.69	
2	S-metolachlor/Linuron	PRE	8.57	0.69	0.0975	5.52	0.69	1.0000
3	Metribuzin	PRE	7.22	0.69	0.0009	6.68	0.69	0.9657
4	Linuron	PRE	9.69	0.69	0.7993	5.88	0.69	1.0000
5	S-metolachlor	PRE	9.87	0.69	0.9144	5.70	0.69	1.0000
6	Pendimethalin (0.5x)	PRE	9.82	0.69	0.8901	5.11	0.69	1.0000
7	Pendimethalin (1x)	PRE	10.18	0.69	0.9947	6.46	0.69	0.9970
8	Pendimethalin (2x)	PRE	8.97	0.69	0.2556	5.88	0.69	1.0000
9	Diclosulam	PRE	4.93	0.69	<0.0001	4.84	0.69	0.9999
10	Flumioxazin	PRE	9.64	0.69	0.7643	6.01	0.69	1.0000
11	Imazethapyr	PRE	10.49	0.69	1.0000	6.59	0.69	0.9848
12	Thifensulfuron	POST	2.47	0.76	<0.0001	0.22	0.76	<0.001
13	Fluazifop	POST	10.94	0.69	1.0000	6.50	0.69	0.9945
14	Fomesafen	POST	9.24	0.69	0.4308	5.52	0.69	1.0000
15	2,4-DB	POST	10.49	0.69	1.0000	5.20	0.69	1.0000
16	Chlorimuron	POST	0.00	0.88	<0.001	0.00	0.76	<0.001
17	Glyphosate	POST	9.46	0.69	0.6136	5.79	0.69	1.0000
18	Sethoxydim	POST	9.87	0.69	0.9144	6.28	0.69	0.9999
19	Flumioxazin	POST	10.18	0.69	0.9947	6.32	0.69	0.9997
20	Imazethapyr	POST	9.96	0.69	0.9525	5.52	0.69	1.0000
21	Between row cultivation	Organic	9.33	0.69	0.5010	5.56	0.69	1.0000
22	Between-within row	Organic	9.42	0.69	0.5754	5.83	0.69	1.0000
23	SoilSaver Black Oat	Organic	8.61	0.69	0.1096	5.38	0.69	1.0000
24	As_033 Black Oat	Organic	10.67	0.69	1.0000	4.48	0.69	0.9767

Table 3.14: Plant density in plants m^2 of *L. albus* cultivar AU Homer as influenced by treatment 3 weeks after POST in 2007 only. Due to heavy rains after POST application in study year 2008 plots were inaccessible.

Treatment			FCU			PBU		
No	Name	Class	Plant Density	StdErr	Dunnett's *P-value*	Plant Density	StdErr	Dunnett's *P-value*
			plants m-2					
1	None	Control	9.91	0.69		8.48	0.69	
2	S-metolachlor/Linuron	PRE	10.85	0.69	0.9945	8.07	0.69	1.0000
3	Metribuzin	PRE	10.90	0.69	0.9906	7.67	0.69	0.9993
4	Linuron	PRE	9.96	0.69	1.0000	8.84	0.69	1.0000
5	S-metolachlor	PRE	9.55	0.69	1.0000	8.21	0.69	1.0000
6	Pendimethalin (0.5x)	PRE	10.27	0.69	1.0000	9.15	0.69	1.0000
7	Pendimethalin (1x)	PRE	9.78	0.69	1.0000	8.48	0.69	1.0000
8	Pendimethalin (2x)	PRE	9.96	0.69	1.0000	7.27	0.69	0.9340
9	Diclosulam	PRE	8.88	0.69	0.9848	6.23	0.69	0.2091
10	Flumioxazin	PRE	10.27	0.69	1.0000	8.66	0.69	1.0000
11	Imazethapyr	PRE	10.54	0.69	1.0000	7.89	0.69	1.0000
12	Thifensulfuron	POST	0.13	0.76	<0.0001	0.00	0.76	<0.0001
13	Fluazifop	POST	9.78	0.69	1.0000	8.16	0.69	1.0000
14	Fomesafen	POST	9.87	0.69	1.0000	7.94	0.69	1.0000
15	2,4-DB	POST	9.87	0.69	1.0000	9.64	0.69	0.9515
16	Chlorimuron	POST	0.00	0.76	<0.0001	0.13	0.76	<0.0001
17	Glyphosate	POST	9.37	0.69	1.0000	7.62	0.69	0.9985
18	Sethoxydim	POST	10.63	0.69	0.9999	8.84	0.69	1.0000
19	Flumioxazin	POST	9.82	0.69	1.0000	8.43	0.69	1.0000
20	Imazethapyr	POST	11.17	0.69	0.9129	8.34	0.69	1.0000
21	Between row cultivation	Organic	9.73	0.69	1.0000	7.98	0.69	1.0000
22	Between-within row	Organic	11.21	0.69	0.8884	8.25	0.69	1.0000
23	SoilSaver Black Oat	Organic	10.45	0.69	1.0000	8.25	0.69	1.0000
24	As_033 Black Oat	Organic	10.00	0.69	1.0000	9.60	0.69	0.9657

Table 3.15: Mean grain yield in kg ha^{-1} of *L. albus* cultivars as influenced by treatments in 2007 and 2008. *P*-values in treatments 12 and 16 in 2007 were obtained by comparison of the non-treated control vs. zero.

	Treatment			ABL 1082			AU Alpha			AU Homer		
Year	No	Name	Class	Mean Yield	StdErr	Dunnett's *P-value*	Mean Yield	StdErr	Dunnett's *P-value*	Mean Yield	StdErr	Dunnet *valu*
							kg ha-1					
2007	1	None	Control	1337	117.9		702	117.9		555	117.9	
	2	S-metolachlor/Linuron	PRE	1331	117.9	1.0000	734	117.9	1.0000	877	117.9	0.2
	3	Metribuzin	PRE	1174	117.9	0.9831	778	125.4	1.0000	551	117.9	1.0
	4	Linuron	PRE	1370	117.9	1.0000	700	117.9	1.0000	729	117.9	0.9
	5	S-metolachlor	PRE	1176	117.9	0.9855	825	117.9	0.9995	671	117.9	0.9
	6	Pendimethalin (0.5x)	PRE	1353	117.9	1.0000	664	117.9	1.0000	740	117.9	0.9
	7	Pendimethalin (1x)	PRE	1256	117.9	1.0000	767	117.9	1.0000	617	117.9	1.0
	8	Pendimethalin (2x)	PRE	1294	117.9	1.0000	719	117.9	1.0000	585	117.9	1.0
	9	Diclosulam	PRE	391	117.9	<0.0001	383	117.9	0.3082	214	117.9	0.2
	10	Flumioxazin	PRE	1305	117.9	1.0000	594	117.9	0.9999	674	117.9	0.9
	11	Imazethapyr	PRE	1323	117.9	1.0000	632	117.9	1.0000	630	117.9	1.0
	12	Thifensulfuron	POST	0	117.9	<0.0001	218	179.0	0.1867	177	132.4	0.1
	13	Fluazifop	POST	1094	117.9	0.6993	893	117.9	0.9306	536	117.9	1.0
	14	Fomesafen	POST	1167	117.9	0.9744	666	117.9	1.0000	666	117.9	0.9
	15	2,4-DB	POST	1216	117.9	0.9996	892	117.9	0.9315	783	117.9	0.7
	16	Chlorimuron	POST	0	117.9	<0.0001	0	117.9	0.9315	143	188.8	0.4
	17	Glyphosate	POST	971	117.9	0.1563	673	117.9	1.0000	634	117.9	1.0
	18	Sethoxydim	POST	1261	117.9	1.0000	706	117.9	1.0000	525	117.9	1.0
	19	Flumioxazin	POST	1229	117.9	0.9999	597	117.9	0.9999	652	117.9	1.0
	20	Imazethapyr	POST	1317	117.9	1.0000	557	117.9	0.9954	695	117.9	0.9
	21	Between row cultivation	Organic	1516	117.9	0.9574	706	117.9	1.0000	812	117.9	0.6
	22	Between-within row	Organic	1379	117.9	1.0000	793	117.9	1.0000	791	117.9	0.7
	23	SoilSaver Black Oat	Organic	1101	117.9	0.7366	550	117.9	0.9917	694	117.9	0.9
	24	As_033 Black Oat	Organic	1000	117.9	0.2424	473	117.9	0.7716	860	117.9	0.3
2008	1	None	Control	2074	162.6		1957	162.6		1219	162.6	
	2	S-metolachlor/Linuron	PRE	1936	162.6	1.0000	1108	162.6	0.0011	1262	162.6	1.0
	3	Metribuzin	PRE	1612	162.6	0.2811	1410	162.6	0.1150	1368	162.6	0.9
	4	Linuron	PRE	2126	162.6	1.0000	1484	162.6	0.2526	1359	162.6	1.0
	5	S-metolachlor	PRE	1910	162.6	0.9998	1426	162.6	0.1384	1027	162.6	0.9
	6	Pendimethalin (0.5x)	PRE	1937	162.6	1.0000	1567	162.6	0.5104	1522	162.6	0.8
	7	Pendimethalin (1x)	PRE	2025	162.6	1.0000	1504	162.6	0.3048	1233	162.6	1.0
	8	Pendimethalin (2x)	PRE	1907	162.6	0.9997	1619	162.6	0.7094	1442	162.6	0.9
	9	Diclosulam	PRE	648	162.6	<0.0001	210	162.6	<0.0001	548	162.6	0.0
	10	Flumioxazin	PRE	1470	162.6	0.0565	1264	162.6	0.0159	1217	162.6	1.0
	11	Imazethapyr	PRE	1742	162.6	0.7320	1460	162.6	0.1984	1309	162.6	1.0
	12	Carfentrazone	POST	2081	162.6	1.0000	1877	162.6	1.0000	1203	162.6	1.0
	13	Fluazifop	POST	1889	162.6	0.9987	1827	162.6	1.0000	1573	162.6	0.6
	14	Fomesafen	POST	1738	162.6	0.7189	1511	162.6	0.3234	1372	162.6	0.9
	15	2,4-DB	POST	2180	162.6	1.0000	1321	162.6	0.0364	1580	162.6	0.6
	16	Plant oil	POST	2195	162.6	1.0000	1618	162.6	0.7065	1347	162.6	1.0
	17	Glyphosate	POST	364	162.6	<0.0001	735	162.6	<0.0001	839	162.6	0.5
	18	Sethoxydim	POST	1941	162.6	1.0000	1309	162.6	0.0309	1313	162.6	1.0
	19	Flumioxazin	POST	1938	162.6	1.0000	1350	162.6	0.0545	1153	162.6	1.0
	20	Imazethapyr	POST	2020	162.6	1.0000	1226	162.6	0.0087	1433	162.6	0.9
	21	Between row cultivation	Organic	2291	162.6	0.9902	1722	162.6	0.9771	1228	162.6	1.0
	22	Between-within row	Organic	1977	162.6	1.0000	1510	162.6	0.3205	1246	162.6	1.0
	23	SoilSaver Black Oat	Organic	1747	162.6	0.7520	1329	162.6	0.0408	1173	162.6	1.0
	24	As_033 Black Oat	Organic	1581	162.6	0.2076	1366	162.6	0.0667	1274	162.6	1.0

Table 3.16: Mean test weight in kg $100L^{-1}$ of *L. albus* cultivars as influenced by treatments in 2007 and 2008. Only the data in which the plot yield was >0.3 kg is included in this table.

Treatment				ABL 1082			AU Alpha			AU Homer		
Year	No	Name	Class	Mean test weight	StdErr	Dunnett's *P-value*	Mean test weight	StdErr	Dunnett's *P-value*	Mean test weight	StdErr	Dunnett's *P-value*
							kg 100L-1					
2007	1	None	Control	80.15	0.46		78.70	0.49		76.29	0.46	
	2	S-metolachlor/Linuron	PRE	81.16	0.46	0.6788	78.83	0.53	1.0000	77.15	0.49	0.9020
	3	Metribuzin	PRE	80.58	0.49	1.0000	78.91	0.49	1.0000	77.00	0.57	0.9931
	4	Linuron	PRE	79.96	0.46	1.0000	79.05	0.49	1.0000	77.48	0.49	0.5309
	5	S-metolachlor	PRE	80.01	0.46	1.0000	78.30	0.49	1.0000	76.83	0.49	0.9992
	6	Pendimethalin (0.5x)	PRE	80.11	0.46	1.0000	78.45	0.49	1.0000	76.48	0.46	1.0000
	7	Pendimethalin (1x)	PRE	80.61	0.46	0.9998	77.51	0.49	0.5702	76.94	0.49	0.9926
	8	Pendimethalin (2x)	PRE	80.79	0.49	0.9920	78.75	0.53	1.0000	76.07	0.46	1.0000
	9	Diclosulam	PRE			0.9920			1.0000			1.0000
	10	Flumioxazin	PRE	79.91	0.46	1.0000	79.18	0.60	1.0000	77.30	0.49	0.7529
	11	Imazethapyr	PRE	80.68	0.46	0.9987	78.45	0.57	1.0000	76.98	0.53	0.9919
	12	Thifensulfuron	POST	N/A			N/A			N/A		
	13	Fluazifop	POST	81.28	0.52	0.6387	78.40	0.46	1.0000	76.70	0.49	1.0000
	14	Fomesafen	POST	80.49	0.49	1.0000	80.03	0.60	0.5919	76.83	0.53	0.9997
	15	2,4-DB	POST	79.93	0.46	1.0000	78.31	0.46	1.0000	77.03	0.46	0.9581
	16	Chlorimuron	POST	N/A			N/A			N/A		
	17	Glyphosate	POST	79.53	0.46	0.9931	78.62	0.49	1.0000	77.96	0.49	0.1192
	18	Sethoxydim	POST	80.31	0.49	1.0000	78.08	0.46	0.9952	75.94	0.49	1.0000
	19	Flumioxazin	POST	80.81	0.49	0.9879	78.75	0.60	1.0000	76.51	0.53	1.0000
	20	Imazethapyr	POST	80.70	0.49	0.9985	78.86	0.53	1.0000	77.27	0.49	0.7851
	21	Between row cultivation	Organic	80.24	0.46	1.0000	77.97	0.46	0.9722	77.05	0.46	0.9510
	22	Between-within row	Organic	80.49	0.46	1.0000	78.56	0.46	1.0000	76.66	0.49	1.0000
	23	SoilSaver Black Oat	Organic	79.50	0.46	0.9881	76.60	0.52	0.0365	76.41	0.49	1.0000
	24	As_033 Black Oat	Organic	78.38	0.46	0.0596	76.11	0.49	0.0018	77.59	0.46	0.3530
2008	1	None	Control	80.08	0.40		76.63	0.40		76.37	0.42	
	2	S-metolachlor/Linuron	PRE	78.49	0.42	0.0393	76.25	0.40	0.9999	76.97	0.42	0.9771
	3	Metribuzin	PRE	79.31	0.40	0.8033	76.43	0.40	1.0000	76.04	0.40	1.0000
	4	Linuron	PRE	78.94	0.40	0.2671	76.91	0.40	1.0000	75.69	0.40	0.9088
	5	S-metolachlor	PRE	79.23	0.40	0.6782	76.62	0.40	1.0000	75.82	0.42	0.9909
	6	Pendimethalin (0.5x)	PRE	79.33	0.40	0.8231	77.19	0.40	0.9821	76.15	0.40	1.0000
	7	Pendimethalin (1x)	PRE	79.44	0.40	0.9412	76.65	0.40	1.0000	76.00	0.40	0.9999
	8	Pendimethalin (2x)	PRE	79.49	0.40	0.9728	76.84	0.40	1.0000	75.70	0.40	0.9248
	9	Diclosulam	PRE	77.94	0.52	0.0080	76.28	1.08	1.0000	75.43	0.40	0.5584
	10	Flumioxazin	PRE	79.44	0.42	0.9575	76.54	0.40	1.0000	76.35	0.40	1.0000
	11	Imazethapyr	PRE	79.17	0.40	0.5752	76.40	0.40	1.0000	75.84	0.42	0.9933
	12	Carfentrazone	POST	79.90	0.40	1.0000	75.97	0.40	0.9236	75.80	0.40	0.9795
	13	Fluazifop	POST	79.41	0.40	0.9207	76.80	0.40	1.0000	76.36	0.42	1.0000
	14	Fomesafen	POST	79.40	0.40	0.9107	76.80	0.40	1.0000	76.10	0.40	1.0000
	15	2,4-DB	POST	79.60	0.40	0.9971	76.76	0.40	1.0000	76.42	0.40	1.0000
	16	Plant oil	POST	80.04	0.40	1.0000	76.69	0.40	1.0000	75.88	0.42	0.9974
	17	Glyphosate	POST	78.77	0.55	0.3860	75.84	0.40	0.7673	76.12	0.54	1.0000
	18	Sethoxydim	POST	78.68	0.40	0.0790	76.07	0.40	0.9832	75.94	0.40	0.9994
	19	Flumioxazin	POST	79.58	0.40	0.9950	76.90	0.40	1.0000	75.17	0.42	0.2665
	20	Imazethapyr	POST	79.74	0.40	1.0000	76.28	0.40	1.0000	75.81	0.40	0.9851
	21	Between row cultivation	Organic	79.87	0.40	1.0000	77.38	0.40	0.8231	75.91	0.42	0.9991
	22	Between-within row	Organic	79.87	0.40	1.0000	76.53	0.40	1.0000	75.76	0.40	0.9658
	23	SoilSaver Black Oat	Organic	79.42	0.40	0.9300	75.84	0.40	0.7620	75.95	0.42	0.9997
	24	As_033 Black Oat	Organic	78.78	0.40	0.1320	76.58	0.40	1.0000	76.23	0.42	1.0000

Table 3.17: Mean seed mass in mg seed^{-1} of *L. albus* cultivars as influenced by treatments in 2007 and 2008. Only data in which seed mass was >160 mg seed^{-1} is included in this table.

	Treatment			ABL 1082			AU Alpha			AU Homer		
Year	No	Name	Class	Mean seed mass	StdErr	Dunnett's *P-value*	Mean seed mass	StdErr	Dunnett's *P-value*	Mean seed mass	StdErr	Dunnett's *P-value*
							mg seed-1					
2007	1	None	Control	199.94	5.98		211.61	5.98		217.98	5.98	
	2	S-metolachlor/Linuron	PRE	211.70	5.98	0.7591	213.69	5.98	1.0000	214.52	5.98	1.0000
	3	Metribuzin	PRE	201.31	5.98	1.0000	209.28	6.35	1.0000	208.41	5.98	0.9317
	4	Linuron	PRE	203.30	5.98	1.0000	211.89	5.98	1.0000	205.84	5.98	0.7192
	5	S-metolachlor	PRE	191.20	5.98	0.9683	207.14	5.98	1.0000	200.17	5.98	0.2148
	6	Pendimethalin (0.5x)	PRE	203.25	5.98	1.0000	206.24	5.98	0.9999	216.33	5.98	1.0000
	7	Pendimethalin (1x)	PRE	200.01	5.98	1.0000	200.99	5.98	0.8643	212.80	5.98	1.0000
	8	Pendimethalin (2x)	PRE	201.54	5.98	1.0000	202.08	6.35	0.9525	203.11	5.98	0.4403
	9	Diclosulam	PRE	178.73	6.35	0.0986	183.43	5.98	0.0044	176.82	5.98	<0.0001
	10	Flumioxazin	PRE	208.41	6.35	0.9834	200.69	5.98	0.8396	207.91	5.98	0.9014
	11	Imazethapyr	PRE	200.99	5.98	1.0000	208.10	6.35	1.0000	222.38	5.98	1.0000
	12	Thifensulfuron	POST	N/A			N/A			N/A		
	13	Fluazifop	POST	192.85	5.98	0.9964	209.74	5.98	1.0000	207.71	5.98	0.8875
	14	Fomesafen	POST	189.49	5.98	0.8754	203.96	5.98	0.9917	208.89	5.98	0.9547
	15	2,4-DB	POST	187.19	5.98	0.6575	213.56	5.98	1.0000	217.68	5.98	1.0000
	16	Chlorimuron	POST	N/A			N/A			N/A		
	17	Glyphosate	POST	188.74	5.98	0.8127	196.51	6.35	0.4761	213.23	5.98	1.0000
	18	Sethoxydim	POST	194.93	5.98	1.0000	213.59	5.98	1.0000	207.25	5.98	0.8516
	19	Flumioxazin	POST	188.75	5.98	0.8140	203.97	5.98	0.9919	215.67	5.98	1.0000
	20	Imazethapyr	POST	189.75	5.98	0.8946	206.96	5.98	1.0000	212.86	5.98	1.0000
	21	Between row cultivation	Organic	203.21	5.98	1.0000	213.28	5.98	1.0000	219.78	5.98	1.0000
	22	Between-within row	Organic	200.70	5.98	1.0000	214.80	5.98	1.0000	217.67	5.98	1.0000
	23	SoilSaver Black Oat	Organic	179.09	5.98	0.0856	208.41	5.98	1.0000	215.96	5.98	1.0000
	24	As_033 Black Oat	Organic	199.89	5.98	1.0000	209.20	5.98	1.0000	204.90	5.98	0.6204
2008	1	None	Control	229.90	5.54		254.68	5.54		254.42	5.54	
	2	S-metolachlor/Linuron	PRE	225.92	5.54	1.0000	245.33	5.54	0.7749	249.10	5.54	0.9989
	3	Metribuzin	PRE	225.75	5.54	1.0000	249.23	5.54	0.9984	255.77	5.54	1.0000
	4	Linuron	PRE	224.60	5.54	0.9989	252.94	5.54	1.0000	251.60	5.54	1.0000
	5	S-metolachlor	PRE	228.34	5.54	1.0000	247.20	5.54	0.9501	244.25	5.54	0.6681
	6	Pendimethalin (0.5x)	PRE	230.77	5.54	1.0000	255.55	5.54	1.0000	256.12	5.54	1.0000
	7	Pendimethalin (1x)	PRE	225.27	5.54	0.9999	251.50	5.54	1.0000	250.20	5.54	1.0000
	8	Pendimethalin (2x)	PRE	230.00	5.54	1.0000	251.93	5.54	1.0000	255.20	5.54	1.0000
	9	Diclosulam	PRE	214.00	5.54	0.1168	242.33	5.79	0.4463	252.92	5.54	1.0000
	10	Flumioxazin	PRE	222.69	5.54	0.9640	249.73	5.54	0.9996	247.77	5.54	0.9833
	11	Imazethapyr	PRE	222.37	5.54	0.9479	249.78	5.54	0.9997	242.32	5.54	0.4214
	12	Carfentrazone	POST	224.67	5.54	0.9991	255.73	5.54	1.0000	252.72	5.54	1.0000
	13	Fluazifop	POST	232.32	5.54	1.0000	255.80	5.54	1.0000	247.91	5.54	0.9866
	14	Fomesafen	POST	231.07	5.54	1.0000	259.28	5.54	0.9999	257.30	5.54	1.0000
	15	2,4-DB	POST	235.02	5.54	0.9993	254.15	5.54	1.0000	256.10	5.54	1.0000
	16	Plant oil	POST	228.17	5.54	1.0000	259.28	5.54	0.9999	263.62	5.54	0.7932
	17	Glyphosate	POST	211.78	6.15	0.0888	230.40	5.54	0.0014	242.54	5.79	0.5009
	18	Sethoxydim	POST	230.40	5.54	1.0000	251.88	5.54	1.0000	261.50	5.54	0.9694
	19	Flumioxazin	POST	225.15	5.54	0.9998	252.83	5.54	1.0000	242.02	5.54	0.3874
	20	Imazethapyr	POST	224.32	5.54	0.9979	247.20	5.54	0.9501	249.95	5.54	0.9999
	21	Between row cultivation	Organic	231.62	5.54	1.0000	249.33	5.54	0.9988	242.92	5.54	0.4941
	22	Between-within row	Organic	227.27	5.54	1.0000	250.78	5.54	1.0000	253.52	5.54	1.0000
	23	SoilSaver Black Oat	Organic	225.72	5.54	1.0000	252.58	5.54	1.0000	253.50	5.54	1.0000
	24	As_033 Black Oat	Organic	226.10	5.54	1.0000	256.05	5.54	1.0000	258.50	5.54	1.0000

IV. EFFECTS OF WEED MANAGEMENT PRACTICES ON YIELD COMPONENTS OF WHITE LUPIN (*LUPINUS ALBUS* L.)

Abstract

White lupin (*Lupinus albus* L.) is of renewed interest in North America as an alternative legume crop with good yield potential and diverse use spectrum. *Lupinus albus* L. can be used as livestock feed, human food and cover crop in conservation agriculture. Because of its slow developing canopy white lupin is very susceptible to weed competition. Therefore effective weed control is necessary. A two-year experiment was established at two sites at E.V. Smith Research and Extension Center of the Alabama Experiment Station to investigate various weed management practices and their effect on plant height and yield components. The weed management schemes evaluated included ten pre-emergence (PRE) and nine post-emergence (POST) herbicide treatments as well as cultural (organic) treatments (two mechanical and two companion crop living mulch weed control measures). All PRE and POST herbicides, with the exceptions of diclosulam, fomesafen and glyphosate, did not affect lupin height, height to the lowest pod, number of fruiting branches and seed yield significantly. Diclosulam induced lupin height reductions about 50%, followed by glyphosate with 30%, which subsequent seed

yield losses. No significant differences were observed between the non-treated control and the organic treatments.

Introduction

Lupinus ssp, belong to the botanical family Fabaceae, and originated in three primary centers: North America, South America and the Mediterranean region (Wilbur, 1963; Wink et al., 1999, Noffsinger and van Santen, 2005). Of the 450 species grown worldwide, only four are of major economical importance: white lupin (*Lupinus albus* L.), yellow lupin (*L. luteus* L.), narrowleafed or blue lupin (*L. angustifolius* L.) and Andean lupin (*L. mutabilis* Sweet) (Bhardwaj, 2002).

White lupin is of interest in the southeastern USA because winter-type cultivars are available. This species was grown successfully in the southeastern United States from the 1930s to the 1950s as a cover crop and for the fixation of nitrogen (Roberson, 1991). After the 1950s white lupin production declined due to loss of government support, freeze damage in two consecutive years and the increased availability of inorganic fertilizers (Payne et al., 2004; van Santen and Reeves, 2003; Noffsinger and van Santen, 2005). Recently, there is renewed interest in this crop in the United States and Canada as an alternative legume crop and for its yield potential. Recent research has been conducted to improve seed quality, genetic improvement for cold, disease and pest tolerance, and determine best management practices (Faluyi, et al., 2000; Payne et al., 2004; Noffsinger and van Santen, 2005). *Lupinus albus* L. is used as livestock feed especially as mid-winter forage for ruminants, as human food and winter cover crop in conservation agriculture (Hill, 1990; Hill, 2005; Noffsinger and van Santen, 2005).

White lupin is a poor weed competitor during early establishment due to a slow canopy development. Effective weed control is necessary to reduce the competition for water, nutrients and lights among *L. albus* L. and weed species (Putnam et al., 1989; Poetsch, 2006).

Yield and yield component development are influenced significantly by the main stem and primary-branch inflorescences, where the main stem is more important in determinate types and the primary-branches in indeterminate types (Noffsinger et al., 2000). Yield components considered are generally pod number m^{-2}, seed number m^{-2}, seed weight, pod weight, seeds per pod and pod yield m^{-2}. It was found that the pod number was the limiting factor in grain yield and that basal branches are of importance for higher yield in the southeastern USA (Noffsinger et al., 2000).

It was found in Pakistan that yield component development of corn (*Zea mays* L.) was affected by weed control methods (Riaz et al., 2007). The authors did not specify the herbicides used in this experiment, but found that all weed control methods significantly affected plant height. Maximum plant height was reached by two combination treatments; mechanical (hoeing) and hand weeding as well as chemical and hand weeding.

Roshdy et al. (2008) found that seed yield increased in canola varieties (*Brassica napus* L.) when weed control methods (hand-hoeing once or twice, pendimethalin) were applied. Pendimethalin, applied PRE, and hand-hoeing twice provided best results:

increase in seed yield, number of pods and 1000 seed weight. It was found that lentil yield was higher in hand-hoed plots than in plots in which herbicides such as linuron and metribuzin were used (Sandhu et al., 1991).

Hoeing is a costly weed management tool and is therefore used primarily in high value crops or as supplement to other weed control practices. It is successful on weed seedlings (Anderson, 1996). With the increasing importance of organic production in US agriculture, the use of alternative, non-chemical weed control practices is required. To be certified as an organic farm a producer has to follow the guidelines of the National Organic Program (NOP) from the seeds used to grow the crops to the final product. The NOP is a program developed by the United States Department of Agriculture and limits the use of synthetic herbicides and therefore other weed control practices such as hoeing are necessary (Cornell Cooperative Extension Publication, 2009).

Cover crops, another non-chemical alternative weed control practice in organic farming and conservation agriculture, have the benefits to lower fertilizer costs, reduce soil erosion, improve soil moisture, enhance organic matter, break pest cycles and cut the use of pesticides (herbicides, insecticides and fungicides) (Bowman et al., 1998). Cover crops out-compete weeds or potentially reduce weed pressure by allelopathy (Anderson, 1996). Black oat (*Avena strigosa* Schreb.), a cool-season annual cereal, has been used successfully for many years as a cover crop for soybean [*Glycine max* (L.) Merr.] in Brazil (Bowman et al., 1998). Black oat is promising cover crop in the southeastern USA due to its exceptional allelopathic activity and large biomass production (Price et al., 2008).

Only three active ingredients are currently registered for the use in *Lupinus* spp: carfentrazone-ethyl, *S*-metolachlor and glyphosate (Crop Protection Reference, 2007). The objective of this experiment is to investigate the use of various weed management practices and their effect on white lupin height and yield components.

Materials and Methods

A two year experiment to investigate the effect of weed management practices on height and yield components of *L. albus* L. was established at two test sites on the E.V. Smith Research and Extension Center of the Alabama Agricultural Experiment Station in October 2007 and 2008 respectively.

Treatment and experiment design

The experiment was a 2 (year) x 2 (location) x 3 (cultivar) x 4 (block) x 24 (weed control) factorial treatment arrangement. The two locations of the experiment were the Field Crops Unit (FCU), near Shorter, AL (32.42 N, 85.88 W) and the Plant Breeding Unit (PBU), Tallassee, AL (32.49 N, 85.89 W). At FCU the experiment was established on a Compass loamy sand (a coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults with a loamy sand surface structure). At PBU the experiment was conducted on a Wickham sandy loam (a fine-loamy, mixed, semiactive, thermic Typic Hapludults with a sandy loam surface structure). The three cultivars used in the experiment were AU Homer (a new high-alkaloid, indeterminate cover crop type), AU Alpha (a new low-alkaloid, indeterminate forage type), and ABL 1082 (low-alkaloid, determinate grain type experimental cultivar). The experimental design was a randomized complete block design (r = 4) nested within each year x location x cultivar combination. The weed control factor had 24 levels: one non-treated control, ten PRE-applied herbicides, nine POST-applied herbicides, two mechanical (hand hoed) weed control treatments as well as two cultural (living mulch) weed control treatments (Table 2.01).

Crop management

Inoculated lupin was seeded in 4 row plots with a John Deer® 1700 four row vacuum planter with a row spacing of 90 cm at a depth of 1.25 cm in October 2007 and October 2008. Seeding density was 17 seeds/m. Smooth seedbeds were prepared one to two weeks prior to planting in 2007. In 2008, the cultivars were planted in raised beds prepared by a KMC 4 row ripper/bedder due to concerns about water logging at both locations. The plot length was 7.5 m at PBU, and 7.5 m and 6 m at FCU in 2007 and 2008, respectively. The PRE herbicide treatments were applied one day after planting in both years. Application of POST herbicides followed 13 (2007) to 16 (2008 due to heavy rainfall) weeks after planting. The cultural control treatments, cv. SoilSaver and As_033 (a selection from PI 436103) black oat (*Avena strigosa* Schreb.), were sown one (2007) to seven days (2008) after seeding of the lupin crop. The mechanical weed control treatments, between row only cultivation and between and within row cultivation, were used twice four (2007) to six (2008) weeks after planting and 18 to 20 (2 blocks at the PBU test site due to heavy rains) weeks after planting. In study year 2007/2008 plots at PBU and FCU were harvested on June 17, 2008. In study year 2008/2009 plots at FCU were harvested on June 16, 2009 and at PBU on June 29, 2009 due to differences in reaching maturity at both locations.

Data collection

At harvest, a random sample of 10 plants per plot (5 from each of the two center rows) were taken to determine yield components attributes such as plant height, number of yield components (main stem, primary and secondary branches, basal branches) and mean yield of each yield component.

Statistical analysis

Generalized linear mixed models procedures as implemented in SAS® PROC GLIMMIX were used to analyze total plant height, height to the lowest pod and yield components. Treatments and location were considered fixed effects. Replicates were considered random. Statistical significance was declared at Dunnett's $P < 0.1$. Total plant height (cm), height to lowest pod (cm), total number of pods per plant and percent of seed number by each yield component, total individual plant seed yield (g $plant^{-1}$) and percent of individual plant seed yield of the yield components were analyzed as normally distributed with R-side modeling of residuals. Treatments 12 and 16 of 2007 and 2008 were excluded from analysis, since these herbicides differed in both years.

Results and Discussion

Plant height

Two-way interactions (year*location and location*cultivar) and three-way interaction (location*treatment*cultivar) for total plant height were not significant. Three-way interactions (year*location*cultivar and location*treatment*cultivar) and four-way interaction (year*location*treatment*cultivar) were not significant for in total height to the lowest pod. The main effects were significant ($\alpha = 0.05$) for the total plant height and the height to the lowest pod (Table 4.01). Results are presented for the year*treatment*cultivar interaction means.

Total plant height varied between among cultivars and years. In 2007 total plant height of the non-treated controls of ABL 1082, AU Alpha and AU Homer were 87, 102 and 107 cm plant^{-1}, respectively (Table 4.02). None of the PRE-applied herbicides, diclosulam excluded, significantly reduced total plant height of either cultivar. Diclosulam reduced the total height of ABL 1082, AU Alpha and AU Homer by over 50% each. Fomesafen was the only POST-applied herbicide that reduced total plant height in 2007, but only the total height of ABL 1082 and AU Alpha was affected. None of the organic herbicide treatments resulted in significant height reduction. Plants of each cultivar treated with between row cultivation were marginally taller than the non-treated control. Sandhu et al. (1991) concluded that hoeing increased space, nutrient and water availability for lentil as compared to a weedy control. Between row cultivation in lupin production may have the same effect. With an increase in space by hoeing the lupin plant can grow taller without having to suffer from significant injury. In 2008 similar results were obtained. Total plant height of the non-treated controls of ABL 1082, AU Alpha and AU Homer was 87, 125 and 117 cm plant^{-1}, respectively. AU Alpha and AU Homer grew 18 and 9 cm taller, respectively as compared to 2007. This may be due to the abundant water supply during the growing period. Again with the exception of diclosulam, none of the PRE-applied herbicides resulted in significant height reduction. Diclosulam reduced total plant height of each cultivar more than 40% as compared to the non-treated control. The POST-applied herbicide treatments, glyphosate excluded, did not significantly reduce the total plant of the cultivars. Unlike in 2007 fomesafen did not cause height reduction. Glyphosate reduced the total plant height of the three cultivars by more than 30% as compared to the non-treated control. Marginally taller ABL 1082 plants were found in plots treated with between row cultivation and SoilSaver black oat in 2008. AU Homer grown with As_033 black oat as a companion crop was up to 8 cm taller than the non-treated control. The height of corn was found to be affected positively by combination treatments of either a chemical plus hand weeding or a mechanical treatment plus hand weeding (Riaz et al., 2007). The problem with the interpretation of these results is that the researchers did not specify which herbicides were used. However, since both of these treatments incorporated the use of hand weeding, it is possible to conclude hand weeding was the most important factor in these treatments. The height of these plants may have been affected by the additional space created by reducing weed density and without causing injury to the plant. This may be the reason why lupin plants, grown in plots in which between row cultivation was applied, grew taller. The significant height reduction by diclosulam is related to the severe injury (Chapter III) this herbicide caused in all three lupin culitvars. The same explanation holds true for the height reduction induced by the application of glyphosate and fomesafen.

The height to the lowest pod of the non-treated controls of ABL 1082 and AU Homer in 2008 was reduced by 10 and 22 cm plant^{-1}, respectively, as compared to 2007 (Table 4.03), whereas the height to the lowest pod of AU Alpha increased by 5.5 cm. Since study year 2008 experienced an abundant water supply all lupin cultivars yielded higher. Grain yield was found to be directly linked to the pod number lupin produces (Noffsinger et al., 2000). The setting of pods may be influenced by water supply, space and nutrients. In 2007 and 2008, diclosulam was the only PRE applied that significantly reduced the height to the lowest pod (>50% in 2007, >30% in 2008). None of the POST-applied herbicides caused significant reduction of the height to the lowest pod in ABL 1082 in 2007. Fomesafen resulted in heights to the lowest pod of AU Alpha and AU Homer of 36 and 60 cm, respectively. This was significantly reduced from the lowest pod height of their non-treated controls (52 cm AU Alpha, 75 cm AU Homer). Glyphosate and fluazifop caused reductions of 20% in lowest pod height in AU Homer in 2007 as compared to the non-treated control. In 2008, glyphosate was the only POST-applied herbicide treatment that reduced lowest pod height. The height of the lowest pod was reduced by 38% (ABL 1082) and 28% (AU Alpha and AU Homer) as compared to their non-treated control with 47, 58 and 53 cm lowest pod, respectively. The reduction in height to the lowest pod induced by fomesafen, glyphosate and diclosulam seems to be direct result of the injuries these herbicides created in the cultivars (Chapter III). None of the organic treatments caused lowest pod height reductions in the cultivars in 2007 and 2008.

Number of fruiting branches

Two-way interactions (year*location and year*treatment) were not significant for the individual number of fruiting branches for the whole plant. and the mainstem and . Three-way interactions were not significant for any of the response variables Main effects for the total fruiting branch number per plant and the percent of individual fruiting branch number by each yield component were significant ($\alpha = 0.05$) (Table 4.04). Results are presented for the treatment main effect means.

Total number of fruiting branches on an individual non-treated control plant was 8.9 (Table 4.05). None of the POST herbicides caused lupin plants to grow significantly higher or lower fruiting branch numbers. With the exception of diclosulam (5.2 branches plant^{-1}), none of the PRE-applied herbicides reduced fruiting branch numbers per plant significantly. The highest rate of pendimethalin (9.9 branches plant^{-1}) produced higher fruiting branch numbers than the non-treated control. This increase was marginally significant. SoilSaver black oat was the only organic weed control treatment that resulted in reduced fruiting branch numbers per plant (7.9).

The main stem yield component (MS-MS) makes up 11 percent of the total individual fruiting branch number in the non-treated control (Table 4.06). All PRE-applied herbicide treatments, diclosulam excluded, had marginally higher and lower percentage. In plants treated with diclosulam MS-MS contributed 20 percent of the individual fruiting branch number. None of the POST-applied herbicides caused the main stem to produce significantly more fruiting branches than the non-treated control. Even though the organic treatments (12-14%) favored a higher percentage of total individual fruiting branch number to be accounted for by MS_MS this was not significant in comparison to the non-treated control.

The primary fruiting branches of the main stem (MS-PB) are the yield components that account for most of the total fruiting branch number of an individual plant (49%) (Table 4.06). This confirms the observation that main stem (in determinate types) and primary fruiting branches (in indeterminate types) are most important for yield and seed number (Noffsinger et al., 2000). Together main stem and primary fruiting branches account for about 60% of the total fruiting branch number of an individual plant. Again diclosulam (56%) is the only PRE-applied herbicide treatments resulted in a higher percentage of fruiting branch numbers produced by MS-PB than the non-treated control. None of the POST-applied herbicides and organic treatments caused a significant reduction or increase of percentage of fruiting branch numbers produced by MS-PB, but all organic treatments marginally increased (50-52%) this fruiting branch number.

The secondary fruiting branches of the main stem (MS-SB) of the non-treated control produced 31 percent of the total individual plant fruiting branch number (Table 4.06). All herbicide treatments (PRE and POST) did not significantly influence the fruiting branch number of MS-SB. The only exception was diclosulam which caused MS-SB to produce significantly lower fruiting branch numbers than on the non-treated control. Only 16 percent of the individual fruiting branch number was produced by MS-SB when treated with this herbicide. Between and within row cultivation was the only organic treatment that caused MS-SB to produce significantly lower fruiting branch numbers than the non-treated control (26%). The main stem yield components account for 90 percent of the total fruiting branch number per plant.

The basal lateral main stem (BL-MS) and fruiting branches (BL-Branch) account for 3 and 4 percent of the individual fruiting branch number of the non-treated control, respectively (Table 4.06). Neither the herbicides nor the organic treatments significantly influenced the fruiting branch numbers of BL-MS and BL-Branch. However, the basal yield components produced marginally higher fruiting branch numbers when the plants were treated with PRE herbicides.

No reasonable explanation for the observations made in plants treated with diclosulam can be found momentarily. AHAS inhibitors such as diclosulam target the main stem and therefore the importance and contribution of MS-MS to the total plant fruiting branch number should have been lower, similarly maybe even on the MS-PB.

Seed yield

The main effects for the total seed yield per plant (g plant^{-1}) and the percent of individual seed yield by each yield component were significant ($\alpha = 0.05$). Two-way interactions were not uniformly significant for the whole plant and yield components. Other interactions were not significant for any of the response variables (Table 4.07). Results are presented for the treatment main effect means.

Individual seed yield of the non-treated control was 24.7 g plant^{-1}. The highest rate of pendimethalin is the only PRE-applied herbicides that caused *Lupinus albus* L. plants to produce higher seed yield (27 g plant^{-1}) (Table 4.08). Pendimethalin was found to induce higher pod numbers in canola varieties (Roshdy et al., 2008). It is possible that with an increase in fruiting branches the number of pods per plant will also be higher. This in turn generated higher yield. This is marginally significant and higher than the non-treated control. Diclosulam reduced individual seed yield by more than 50% (11 g). With 21.71 and 22.02 g plant^{-1}, respectively, fomesafen and glyphosate are the only POST herbicides that resulted in significantly lower seed yield per plant than the non-treated control. Of all the organic treatments, SoilSaver black oat caused significant lower seed yield per plant (20 g plant^{-1}).

The main stem (MS-MS) accounts for 26 percent of the individual plant seed yield in the non-treated control. None of the herbicides and organic treatments significantly influenced the seed yield produced by MS-MS. The only exception was diclosulam which caused plants to produce 36 percent of the total seed yield by MS-MS. This conforms to the observed fruiting branch numbers in the MS-MS.

The percentage of individual plant seed yield of primary fruiting branches of the main stem (MS-PB) were not significantly increased or reduced by any treatment compared to the non-treated control (52%) (Table 4.09). The secondary fruiting branches of the main stem (MS-SB) accounted for 15 percent of the total plant seed yield of the non-treated control. With the exception of diclosulam, none of the herbicides and organic treatments significantly reduced the seed yield of MS-SB. Only 6 percent of the total seed yield of a plant treated with diclosulam was produced by MS-SB. However 7 percent of the individual seed yield of plants treated with diclosulam was produced by the basal main stem (BL-MS). This is significantly higher than what BL-MS contributes to the individual yield in the non-treated control (4%). The higher yield contribution of BL-MS in diclosulam plants is particularly interesting to note, since the percentage of individual fruiting branch number of BL-MS (Table 4.06) was not significantly higher. None of the other treatments influenced BL-MS yield significantly. The basal fruiting branches (BL-Branch) produced 3 percent of the individual plant seed yield. Neither the herbicides nor the organic treatments significantly altered the yield contribution of BL-Branch.

Pod number was found to be the limiting factor for grain yield in white lupin (Noffsinger et al., 2000). The total number of fruiting branches and maybe subsequently pod numbers in plants treated with diclosulam were low which induced seed yield loss per individual plant (Table 4.08) and grain yield in kg ha^{-1} (Table 3.15). Hand-hoeing did not significantly increase fruiting branch number and seed yield. Therefore, it can be concluded that the influence, hand-hoeing has on lupin cultivars to increase yield and number of yield components, is not as strong as it is on some canola varieties (Roshdy et al., 2008).

In general, future research is needed to investigate the specific effects of weed control treatments that are particularly successful in this study, i.e. the highest rate of pendimethalin, the *S*-metolachlor/linuron mixture, imazethapyr (PRE and POST), 2,4-DB, sethoxydim, fluazifop and organic herbicide treatments, on yield component development and yield. Additional companion crops may be included, i.e. rye. Diclosulam, fomesafen and glyphosate should be excluded from future experiments in white lupin, because these herbicides caused significant height and yiel reductions.

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Table 4.01: *P*-values from the analysis of variance for individual plant height (cm $plant^{-1}$) and height to lowest pod.

		Response variables	
Effect	DF	Plant height	Height to lowest pod
Loc	1	<0.0001	<0.0001
Year	1	<0.0001	<0.0001
Year*Loc	1	0.0076	0.0001
Cultivar	2	<0.0001	<0.0001
Loc*Cultivar	2	0.5821	0.0082
Year*Cultivar	2	<0.0001	0.0000
Year*Loc*Cultivar	2	<0.0001	0.0665
Trt_N	21	<0.0001	<0.0001
Loc*Trt_N	21	<0.0001	<0.0001
Year*Trt_N	21	<0.0001	<0.0001
Year*Loc*Trt_N	21	0.0003	0.0178
Trt_N*Cultivar	42	0.0000	0.0011
Loc*Trt_N*Cultivar	42	0.0970	0.4082
Year*Trt_N*Cultivar	42	<0.0001	0.0053
Year*Loc*Trt_N*Culti	42	0.0033	0.5757

Table 4.02: Total plant height in cm of *L. albus* L cultivars ABL 1082, AU Alpha and AU Homer as influenced by treatment in 2007 and 2008.

	Treatment			ABL 1082			AU Alpha			AU Homer		
Year	No	Name	Class	Mean	SE	Dunnett's *P-value*	Mean	SE	Dunnett's *P-value*	Mean	SE	Dunnett's *P-value*
				cm plant^{-1}								
2007	1	None	Control	87	3.44		102	3.79		107	4.25	
	2	S-metolachlor/Linuron	PRE	89	3.44	1.0000	99	3.79	1.0000	113	4.25	0.9617
	3	Metribuzin	PRE	80	3.27	0.5581	98	3.94	0.9989	111	4.25	1.0000
	4	Linuron	PRE	88	3.27	1.0000	106	3.79	0.9991	116	4.53	0.6759
	5	S-metolachlor	PRE	84	3.27	0.9997	95	3.79	0.7427	106	4.25	1.0000
	6	Pendimethalin (0.5x)	PRE	90	3.27	0.9980	98	3.79	0.9958	114	4.25	0.9556
	7	Pendimethalin (1x)	PRE	83	3.27	0.9860	102	3.94	1.0000	112	4.25	0.9988
	8	Pendimethalin (2x)	PRE	85	3.27	1.0000	97	3.79	0.9731	111	4.25	0.9997
	9	Diclosulam	PRE	45	3.27	<0.0001	58	3.79	<0.0001	55	4.25	<0.0001
	10	Flumioxazin	PRE	84	3.44	0.9996	98	3.79	0.9964	114	4.25	0.8758
	11	Imazethapyr	PRE	85	3.27	1.0000	99	3.79	1.0000	111	4.25	0.9998
	13	Fluazifop	POST	77	3.27	0.1178	99	3.79	1.0000	101	4.53	0.9871
	14	Fomesafen	POST	73	3.27	0.0037	80	3.79	<0.0001	97	4.25	0.5530
	15	2,4-DB	POST	88	3.27	1.0000	100	4.10	1.0000	108	4.25	1.0000
	17	Glyphosate	POST	79	3.27	0.2906	92	3.79	0.2809	103	4.25	0.9999
	18	Sethoxydim	POST	84	3.27	0.9972	105	4.67	1.0000	107	4.25	1.0000
	19	Flumioxazin	POST	75	3.27	0.0325	93	3.94	0.5335	101	4.25	0.9574
	20	Imazethapyr	POST	79	3.27	0.3138	95	3.79	0.7507	106	4.25	1.0000
	21	Between row cultivation	Organic	89	3.27	1.0000	104	3.79	1.0000	115	4.53	0.8650
	22	Between-within row	Organic	81	3.27	0.7345	100	3.79	1.0000	114	4.53	0.9092
	23	SoilSaver Black Oat	Organic	81	3.27	0.6760	101	4.10	1.0000	103	4.53	0.9998
	24	As_033 Black Oat	Organic	88	3.27	1.0000	89	3.79	0.0838	109	4.25	1.0000
2008	1	None	Control	87	3.79		125	3.27		117	3.79	
	2	S-metolachlor/Linuron	PRE	77	3.79	0.2703	125	3.27	1.0000	116	3.79	1.0000
	3	Metribuzin	PRE	80	3.79	0.7660	120	3.27	0.8407	117	3.79	1.0000
	4	Linuron	PRE	88	3.79	1.0000	124	3.27	1.0000	119	3.79	1.0000
	5	S-metolachlor	PRE	84	3.79	0.9998	124	3.27	1.0000	108	3.79	0.3958
	6	Pendimethalin (0.5x)	PRE	85	3.79	1.0000	127	3.27	1.0000	122	3.79	0.9675
	7	Pendimethalin (1x)	PRE	86	3.79	1.0000	126	3.27	1.0000	120	3.79	1.0000
	8	Pendimethalin (2x)	PRE	86	3.79	1.0000	122	3.27	0.9985	119	3.79	1.0000
	9	Diclosulam	PRE	55	3.79	<0.0001	49	3.27	<0.0001	64	3.79	<0.0001
	10	Flumioxazin	PRE	75	3.79	0.1168	119	3.27	0.6644	112	3.79	0.9937
	11	Imazethapyr	PRE	84	3.79	0.9989	121	3.27	0.9407	112	3.79	0.9947
	13	Fluazifop	POST	85	3.79	1.0000	126	3.27	1.0000	116	3.79	1.0000
	14	Fomesafen	POST	78	3.79	0.3916	120	3.27	0.7559	112	3.79	0.9860
	15	2,4-DB	POST	86	3.79	1.0000	131	3.27	0.6596	121	3.79	0.9979
	17	Glyphosate	POST	56	3.79	<0.0001	88	3.27	<0.0001	79	3.79	<0.0001
	18	Sethoxydim	POST	86	3.79	1.0000	128	3.27	0.9997	116	3.79	1.0000
	19	Flumioxazin	POST	83	3.79	0.9982	123	3.27	1.0000	109	3.79	0.5790
	20	Imazethapyr	POST	80	3.79	0.7625	121	3.27	0.9256	116	3.79	1.0000
	21	Between row cultivation	Organic	88	3.79	1.0000	124	3.27	1.0000	111	3.79	0.9201
	22	Between-within row	Organic	82	3.79	0.9184	124	3.27	1.0000	110	3.79	0.8031
	23	SoilSaver Black Oat	Organic	88	3.79	1.0000	123	3.27	0.9999	115	3.79	1.0000
	24	As_033 Black Oat	Organic	88	3.79	1.0000	122	3.27	0.9887	125	3.79	0.6370

Table 4.03: Height to the lowest pod in cm of *L. albus* L. cultivars ABL 1082, AU Alpha and AU Homer as influenced by treatment in 2007 and 2008.

	Treatment			ABL 1082			AU Alpha			AU Homer		
Year	No	Name	Class	Mean	SE	Dunnett's *P-value*	Mean	SE	Dunnett's *P-value*	Mean	SE	Dunnett's *P-value*
				cm $plant^{-1}$								
2007	1	None	Control	57	3.56		52	2.84		75	3.32	
	2	S-metolachlor/Linuron	PRE	56	3.56	1.0000	50	2.84	1.0000	76	3.32	1.0000
	3	Metribuzin	PRE	49	3.32	0.6086	48	2.94	0.9868	76	3.32	1.0000
	4	Linuron	PRE	55	3.32	1.0000	59	2.84	0.6288	70	3.56	0.9407
	5	S-metolachlor	PRE	54	3.32	1.0000	47	2.84	0.7377	67	3.32	0.5888
	6	Pendimethalin (0.5x)	PRE	58	3.32	1.0000	51	2.84	1.0000	75	3.32	1.0000
	7	Pendimethalin (1x)	PRE	51	3.32	0.8875	54	2.94	1.0000	65	3.32	0.2247
	8	Pendimethalin (2x)	PRE	52	3.32	0.9931	48	2.84	0.9513	73	3.32	1.0000
	9	Diclosulam	PRE	27	3.32	<0.0001	29	2.84	<0.0001	33	3.32	<0.0001
	10	Flumioxazin	PRE	52	3.56	0.9901	49	2.84	0.9911	74	3.32	1.0000
	11	Imazethapyr	PRE	52	3.32	0.9947	52	2.84	1.0000	72	3.32	0.9999
	13	Fluazifop	POST	49	3.32	0.6731	49	2.84	0.9988	61	3.56	0.0268
	14	Fomesafen	POST	45	3.32	0.1012	36	2.84	0.0002	60	3.32	0.0083
	15	2,4-DB	POST	57	3.32	1.0000	53	3.11	1.0000	66	3.32	0.4069
	17	Glyphosate	POST	49	3.32	0.6619	49	2.84	0.9988	60	3.32	0.0063
	18	Sethoxydim	POST	54	3.32	0.9999	55	3.60	0.9999	76	3.32	1.0000
	19	Flumioxazin	POST	48	3.32	0.3997	50	2.94	1.0000	66	3.32	0.2924
	20	Imazethapyr	POST	50	3.32	0.7037	49	2.84	0.9969	70	3.32	0.9367
	21	Between row cultivation	Organic	55	3.32	1.0000	51	2.84	1.0000	69	3.56	0.8899
	22	Between-within row	Organic	52	3.32	0.9627	50	2.84	0.9998	69	3.56	0.9380
	23	SoilSaver Black Oat	Organic	54	3.32	1.0000	57	3.11	0.9524	67	3.56	0.5892
	24	As_033 Black Oat	Organic	58	3.32	1.0000	49	2.84	0.9934	67	3.32	0.4171
2008	1	None	Control	47	2.25		58	2.25		53	2.25	
	2	S-metolachlor/Linuron	PRE	40	2.25	0.1471	54	2.25	0.8900	53	2.25	1.0000
	3	Metribuzin	PRE	44	2.25	0.9992	54	2.25	0.6883	54	2.25	1.0000
	4	Linuron	PRE	45	2.25	1.0000	60	2.25	0.9986	55	2.25	1.0000
	5	S-metolachlor	PRE	47	2.25	1.0000	57	2.25	1.0000	50	2.25	0.8765
	6	Pendimethalin (0.5x)	PRE	46	2.25	1.0000	60	2.25	0.9991	57	2.25	0.9354
	7	Pendimethalin (1x)	PRE	43	2.25	0.8695	61	2.25	0.9636	56	2.25	0.9962
	8	Pendimethalin (2x)	PRE	44	2.25	0.9963	58	2.25	1.0000	54	2.25	1.0000
	9	Diclosulam	PRE	31	2.25	<0.0001	25	2.25	<0.0001	29	2.25	<0.0001
	10	Flumioxazin	PRE	37	2.25	0.0032	53	2.25	0.4653	50	2.25	0.9006
	11	Imazethapyr	PRE	43	2.25	0.8900	53	2.25	0.6349	53	2.25	1.0000
	13	Fluazifop	POST	45	2.25	1.0000	56	2.25	1.0000	55	2.25	1.0000
	14	Fomesafen	POST	42	2.25	0.6413	53	2.25	0.3717	49	2.25	0.5729
	15	2,4-DB	POST	46	2.25	1.0000	59	2.25	1.0000	55	2.25	1.0000
	17	Glyphosate	POST	30	2.25	<0.0001	42	2.25	<0.0001	38	2.25	<0.0001
	18	Sethoxydim	POST	48	2.25	1.0000	60	2.25	0.9947	53	2.25	1.0000
	19	Flumioxazin	POST	46	2.25	1.0000	56	2.25	0.9998	51	2.25	0.9986
	20	Imazethapyr	POST	44	2.25	0.9837	57	2.25	1.0000	53	2.25	1.0000
	21	Between row cultivation	Organic	48	2.25	1.0000	58	2.25	1.0000	54	2.25	1.0000
	22	Between-within row	Organic	43	2.25	0.8834	60	2.25	0.9999	50	2.25	0.9697
	23	SoilSaver Black Oat	Organic	47	2.25	1.0000	61	2.25	0.9800	54	2.25	1.0000
	24	As_033 Black Oat	Organic	48	2.25	1.0000	57	2.25	1.0000	57	2.25	0.7631

Table 4.04: *P*-values from the analysis of variance for number of fruiting branches per plant and yield per plant expressed as a fraction of whole plant branch number: Mainstem-Mainstem (MS-MS), Mainstem-Primary Branches (MS-PB), Mainstem-Secondary Branches (MS-SB), Basal-Mainstem (BL-MS) and Basal branch (BL-Branch).

		Response variables					
Effect	DF	Whole Plant	MS-MS	MS-PB	MS-SB	BL-MS	BL-Branch
Loc	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year	1	<0.0001	0.0018	<0.0001	<0.0001	0.0385	<0.0001
Year*Loc	1	0.7086	0.1870	<0.0001	0.0058	<0.0001	<0.0001
Cultivar	2	<0.0001	0.0133	<0.0001	<0.0001	<0.0001	<0.0001
Loc*Cultivar	2	0.0253	0.0014	<0.0001	<0.0001	<0.0001	<0.0001
Year*Cultivar	2	0.0034	0.0002	0.4572	0.0531	0.0265	0.0465
Year*Loc*Cultivar	2	0.0071	0.7064	<0.0001	0.0001	0.0539	0.0195
Trt_N	21	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Loc*Trt_N	21	0.0103	0.0047	<0.0001	<0.0001	0.6367	0.0003
Year*Trt_N	21	0.1509	0.0596	0.0732	0.0040	0.0252	<0.0001
Year*Loc*Trt_N	21	0.2757	0.0768	0.1113	0.2348	0.8584	0.6133
Trt_N*Cultivar	42	0.1929	0.0009	0.3408	0.5751	0.9613	0.1318
Loc*Trt_N*Cultivar	42	0.0487	0.0332	0.0866	0.0001	0.0009	0.0647
Year*Trt_N*Cultivar	42	0.2294	0.0818	0.2439	0.0571	0.0305	0.2872
Year*Loc*Trt_N*Cultivar	42	0.4185	0.7219	0.3459	0.3558	0.3899	0.8601

Table 4.05: Individual plant fruiting branch number as affected by treatment over the cultivars, both locations and years. Treatments 12 and 16 were excluded.

Treatment			Whole Plant		
No	Name	Class	Mean	SE	Dunnett's *P*-*value*
			number plant^{-1}		
1	None	Control	8.91	0.3254	
2	S-metolachlor/Linuron	PRE	9.00	0.3254	1.0000
3	Metribuzin	PRE	8.98	0.3254	1.0000
4	Linuron	PRE	9.39	0.3212	0.9746
5	S-metolachlor	PRE	8.58	0.3212	0.9998
6	Pendimethalin (0.5x)	PRE	9.07	0.3212	1.0000
7	Pendimethalin (1x)	PRE	9.45	0.3212	0.9329
8	Pendimethalin (2x)	PRE	9.97	0.3212	0.1754
9	Diclosulam	PRE	5.25	0.3212	<0.0001
10	Flumioxazin	PRE	9.37	0.3212	0.9845
11	Imazethapyr	PRE	8.91	0.3212	1.0000
13	Fluazifop	POST	8.95	0.3254	1.0000
14	Fomesafen	POST	8.87	0.3212	1.0000
15	2,4-DB	POST	9.06	0.3254	1.0000
17	Glyphosate	POST	9.06	0.3212	1.0000
18	Sethoxydim	POST	8.80	0.3254	1.0000
19	Flumioxazin	POST	8.54	0.3212	0.9989
20	Imazethapyr	POST	8.70	0.3212	1.0000
21	Between row cultivation	Organic	9.00	0.3254	1.0000
22	Between-within row	Organic	8.57	0.3212	0.9997
23	SoilSaver Black Oat	Organic	7.89	0.3254	0.2310
24	As_033 Black Oat	Organic	8.61	0.3212	1.0000

Table 4.06: Fraction of plant fruiting branch number of main stem and basal yield components [Main stem (MS-MS), Primary- (MS-PB) and Secondary branches (MS-SB), Basal-Main stem (BL-MS) and Basal-Branch (BL-Branch)] as influenced by treatment over cultivars, locations and years. Branch number of individual plant is given in Table 4.05.

Treatment			MS-MS		MS-PB		MS-SB		BL-MS		BL-Branch	
No	Name	Class	Mean	Dunnett's *P*-*value*	Mean	Dunnett's *P*-*value*	Mean	Dunnett's *P*-*value*	Mean	Dunnett's *P*-*value*	Mean	Dunnett's *P*-*value*
			fraction of individual branch number									
1	None	Control	0.11		0.49		0.31		0.03		0.05	
2	S-metolachlor/Linuron	PRE	0.11	1.0000	0.49	1.0000	0.27	0.1502	0.05	0.0036	0.08	0.4178
3	Metribuzin	PRE	0.11	1.0000	0.49	1.0000	0.29	0.1184	0.04	0.7250	0.07	0.8190
4	Linuron	PRE	0.11	1.0000	0.47	0.7844	0.28	0.3595	0.05	0.0046	0.10	0.0010
5	S-metolachlor	PRE	0.12	0.9580	0.50	1.0000	0.29	0.1756	0.04	0.9446	0.05	1.0000
6	Pendimethalin (0.5x)	PRE	0.11	1.0000	0.47	0.9031	0.31	0.7354	0.04	0.8692	0.07	0.8720
7	Pendimethalin (1x)	PRE	0.10	0.9959	0.48	1.0000	0.30	0.4077	0.04	0.7152	0.08	0.2423
8	Pendimethalin (2x)	PRE	0.10	0.9436	0.46	0.5509	0.31	0.7355	0.05	0.0392	0.08	0.0704
9	Diclosulam	PRE	0.20	<0.0001	0.56	0.0017	0.16	<0.0001	0.04	0.9688	0.05	0.9995
10	Flumioxazin	PRE	0.11	1.0000	0.48	0.9999	0.27	0.1150	0.05	0.0210	0.10	0.0025
11	Imazethapyr	PRE	0.11	1.0000	0.49	1.0000	0.30	0.3600	0.04	0.9809	0.06	1.0000
13	Fluazifop	POST	0.13	0.2752	0.49	1.0000	0.30	0.4385	0.03	1.0000	0.05	1.0000
14	Fomesafen	POST	0.12	0.9893	0.49	1.0000	0.29	0.1621	0.04	0.9768	0.07	0.9662
15	2,4-DB	POST	0.11	1.0000	0.46	0.4615	0.34	0.1400	0.03	1.0000	0.05	1.0000
17	Glyphosate	POST	0.09	0.6223	0.51	0.9917	0.31	0.7551	0.03	0.9999	0.06	1.0000
18	Sethoxydim	POST	0.12	0.9776	0.49	1.0000	0.31	0.9086	0.03	1.0000	0.05	1.0000
19	Flumioxazin	POST	0.11	1.0000	0.49	1.0000	0.31	0.9945	0.03	1.0000	0.05	1.0000
20	Imazethapyr	POST	0.11	1.0000	0.48	1.0000	0.29	0.1978	0.04	0.3666	0.07	0.8066
21	Between row cultivation	Organic	0.12	0.9999	0.50	1.0000	0.30	0.4405	0.03	1.0000	0.05	1.0000
22	Between-within row	Organic	0.12	1.0000	0.51	0.9362	0.26	0.0187	0.04	0.0858	0.06	0.9945
23	SoilSaver Black Oat	Organic	0.14	0.0766	0.52	0.5973	0.30	0.4725	0.02	0.1704	0.02	0.0808
24	As_033 Black Oat	Organic	0.12	0.9892	0.50	1.0000	0.32	0.7143	0.02	0.9191	0.04	0.6381
SE			0.01		0.01		0.011		0.004		0.01	

Table 4.07: *P*-values from the analysis of variance for whole plant seed yield (g plant-1) and yield components expressed as a fraction of whole plant yield: Mainstem-Mainstem (MS-MS), Mainstem-Primary Branches (MS-PB), Mainstem-Secondary Branches (MS-SB), Basal-Mainstem (BL-MS) and Basal branch (BL-Branch).

		Response variables					
Effect	DF	Whole Plant	MS-MS	MS-PB	MS-SB	BL-MS	BL-Branch
Loc	1	<0.0001	<0.0001	<0.0001	<0.0001	0.0356	<0.0001
Year	1	0.0013	0.2068	<0.0001	<0.0001	0.0011	0.0310
Year*Loc	1	<0.0001	0.6033	0.0001	<0.0001	<0.0001	<0.0001
Cultivar	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Loc*Cultivar	2	0.0001	0.0307	0.0009	<0.0001	<0.0001	0.0004
Year*Cultivar	2	0.0002	<0.0001	<0.0001	0.0038	0.3270	0.0033
Year*Loc*Cultivar	2	0.0003	0.2407	0.2043	0.1334	0.0198	0.0008
Trt_N	21	<0.0001	<0.0001	0.0012	<0.0001	<0.0001	<0.0001
Loc*Trt_N	21	0.0020	0.0114	0.0004	<0.0001	0.1092	0.0252
Year*Trt_N	21	0.1566	0.0001	0.0442	0.0001	0.0287	0.0006
Year*Loc*Trt_N	21	0.0741	0.0023	<0.0001	<0.0001	0.0979	0.5325
Trt_N*Cultivar	42	0.1810	0.0059	0.0354	0.0154	0.3929	0.7484
Loc*Trt_N*Cultivar	42	0.1836	0.3193	0.4318	0.0022	<0.0001	0.7023
Year*Trt_N*Cultivar	42	0.1585	0.0897	0.1067	0.0791	0.0099	0.8575
Year*Loc*Trt_N*Cultivar	42	0.5152	0.0790	0.1345	0.1818	0.1715	0.4066

Table 4.08: Individual plant seed yield in g as affected by treatment. Treatments 12 and 16 were excluded.

Treatment			Whole Plant		
No	Name	Class	Mean	SE	Dunnett's *P-value*
			g $plant^{-1}$		
1	None	Control	24.7	0.52	
2	S-metolachlor/Linuron	PRE	24.0	0.60	0.6563
3	Metribuzin	PRE	23.9	0.53	0.6251
4	Linuron	PRE	23.0	0.54	0.2776
5	S-metolachlor	PRE	23.4	0.55	0.4014
6	Pendimethalin (0.5x)	PRE	24.0	0.55	0.6800
7	Pendimethalin (1x)	PRE	25.6	0.58	0.5541
8	Pendimethalin (2x)	PRE	27.1	0.51	0.1061
9	Diclosulam	PRE	11.2	0.52	<0.0001
10	Flumioxazin	PRE	26.0	0.56	0.3910
11	Imazethapyr	PRE	23.9	0.55	0.6367
13	Fluazifop	POST	24.6	0.54	0.9831
14	Fomesafen	POST	21.7	0.58	0.0558
15	2,4-DB	POST	25.2	0.58	0.7505
17	Glyphosate	POST	22.0	0.53	0.0876
18	Sethoxydim	POST	24.0	0.59	0.6752
19	Flumioxazin	POST	22.6	0.54	0.1754
20	Imazethapyr	POST	23.0	0.54	0.2769
21	Between row cultivation	Organic	25.8	0.54	0.4532
22	Between-within row	Organic	24.0	0.52	0.6782
23	SoilSaver Black Oat	Organic	20.2	0.58	0.0550
24	As_033 Black Oat	Organic	22.7	0.54	0.1978

Table 4.09: Fraction of individual plant seed yield (expressed as fraction) of main stem and basal yield components [Main stem (MS-MS), Primary- (MS-PB) and Secondary branches (MS-SB), Basal-Main stem (BL-MS) and Basal-Branch (BL-Branch)] as influenced by treatment over cultivars, locations and years. Actual plant seed yield in g is in Table 4.08.

Treatment			MS-MS		MS-PB		MS-SB		BL-MS		BL-Branch	
No	Name	Class	Mean	Dunnett's *P-value*	Mean	Dunnett's *P-value*	Mean	Dunnett's *P-value*	Mean	Dunnett's *P-value*	Mean	Dunnett's *P-value*
			fraction of total plant seed yield									
1	None	Control	0.26		0.52		0.15		0.04		0.03	
2	S-metolachlor/Linuron	PRE	0.24	0.9987	0.51	0.9999	0.14	0.9980	0.08	0.0764	0.04	0.7385
3	Metribuzin	PRE	0.27	0.9999	0.49	0.9238	0.13	0.8461	0.06	0.8428	0.04	0.3796
4	Linuron	PRE	0.24	0.9973	0.47	0.2767	0.14	0.9838	0.08	0.0403	0.05	0.0320
5	S-metolachlor	PRE	0.28	0.9728	0.50	0.9987	0.13	0.9202	0.06	0.9628	0.03	1.0000
6	Pendimethalin (0.5x)	PRE	0.27	1.0000	0.50	0.9990	0.14	0.9755	0.06	0.8758	0.03	1.0000
7	Pendimethalin (1x)	PRE	0.23	0.7699	0.52	1.0000	0.15	1.0000	0.07	0.2137	0.04	0.8482
8	Pendimethalin (2x)	PRE	0.22	0.3419	0.52	1.0000	0.15	1.0000	0.08	0.0581	0.04	0.6585
9	Diclosulam	PRE	0.36	<0.0001	0.47	0.1298	0.06	<0.0001	0.07	0.0822	0.02	0.9890
10	Flumioxazin	PRE	0.23	0.9265	0.51	1.0000	0.12	0.2931	0.08	0.0077	0.05	0.0637
11	Imazethapyr	PRE	0.26	1.0000	0.53	1.0000	0.12	0.2978	0.06	0.9474	0.03	1.0000
13	Fluazifop	POST	0.27	1.0000	0.50	0.9831	0.16	1.0000	0.05	1.0000	0.02	1.0000
14	Fomesafen	POST	0.28	0.9557	0.48	0.3987	0.15	1.0000	0.05	0.9983	0.03	0.9916
15	2,4-DB	POST	0.24	0.9988	0.53	1.0000	0.15	1.0000	0.05	0.9989	0.02	1.0000
17	Glyphosate	POST	0.21	0.2942	0.57	0.2114	0.13	0.8015	0.05	1.0000	0.03	0.9800
18	Sethoxydim	POST	0.26	1.0000	0.50	0.9842	0.17	0.8981	0.04	1.0000	0.03	1.0000
19	Flumioxazin	POST	0.26	1.0000	0.51	1.0000	0.14	0.9997	0.05	0.9960	0.04	0.7027
20	Imazethapyr	POST	0.25	1.0000	0.50	0.9971	0.15	1.0000	0.06	0.8389	0.04	0.9086
21	Between row cultivation	Organic	0.27	1.0000	0.53	1.0000	0.13	0.7758	0.05	1.0000	0.02	1.0000
22	Between-within row	Organic	0.28	0.9936	0.49	0.8316	0.12	0.3792	0.07	0.1197	0.03	0.9673
23	SoilSaver Black Oat	Organic	0.31	0.0825	0.50	0.9664	0.16	1.0000	0.02	0.4653	0.01	0.6112
24	As_033 Black Oat	Organic	0.29	0.7135	0.50	0.9981	0.16	1.0000	0.03	0.9929	0.02	0.9890
SE			0.01		0.02		0.01		0.01		0.01	