Evaluation of Herbicide Efficacy, Injury, and Yield in White Lupin (*Lupinus albus* L.)

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Abstract

White lupin is of increasing interest in the southeastern United States (US) as a winter legume cover crop or as mid-winter forage for ruminants. White lupins are poor weed competitors during early establishment, making effective weed control necessary; however, only three herbicides are currently registered for use in lupin. An experiment was conducted at two Alabama sites in 2007 and 2008 to evaluate herbicide efficacy provided by ten preemergence (PRE) and nine postemergence (POST) herbicides as well as lupin injury and yield. Overall, PRE applied herbicides, particularly imazethapyr, linuron, and flumioxazin, caused less crop injury than POST herbicides while providing ≥ 86% control of annual bluegrass, corn spurry, heartwing sorrel, henbit, and lesser swinecress six weeks after application. Grass-active herbicides, fluazifop and sethoxydim, provided greater than 95% of annual bluegrass control without causing unrecoverable lupin damage. Imazethapyr applied POST controlled shepherd’s purse (96% to 98%), cutleaf evening-primrose (81% to 96%), and wild radish (71% to 99%) without lupin injury. POST-directed spray applications of glyphosate and flumioxazin provided good weed control of corn spurry (80% to 98%) and winter vetch (71% to 95%) but caused significant crop injury due to drift. In general, grain yields were only reduced with the use of chlorimuron, diclosulam, glyphosate, and thifensulfuron. This research suggests there are several herbicides not currently registered that could be beneficial for use in US lupin production.

Keywords: Alternative nitrogen source, cover crop, weed contro

1. Introduction

Conventional agriculture depends on synthetic nitrogen (N) fertilizers and herbicides for high crop performance [1]. Alternative N sources are available in the form of leguminous crops such
as *Lupinus* spp. White lupin is of major interest in the southeastern US because new cultivars exhibit differential vernalization requirements similar to wheat (*Triticum aestivum* L.) and can be utilized as mid-winter forage. White lupin has been utilized in the southeastern US as a livestock feed, for human consumption and as a winter cover crop in conservation agriculture [2, 3]. Since its introduction in the 1930s, until the 1950s the US lupin production reached over 1 million ha; however, production declined with the loss of government support, cold-weather damage to seed nurseries, and the increased availability of inorganic fertilizers [3-5].

*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. Lupin reaches maximum vegetative growth during flowering when it can successfully compete with newly emerging weeds [6]. Effective weed control is necessary to ensure lupin success under competition with weed species for water, nutrients, and light [6, 7].

Previous research has been conducted to compare the effectiveness of herbicides on weed control and potential for crop injury in lupin. A successful preemergence (PRE) herbicide treatment resulting in no crop damage is pendimethalin alone, or in combination with metribuzin [8, 9]. Pendimethalin use in white lupin provided 100% control of Russian thistle (*Salsola tragus* L.) and prostrate knotweed (*Polygonum aviculare* L.) [10]. The use of PRE applied metolachlor and alachlor, primarily in mixes with other herbicides, successfully controlled annual grasses and some broadleaf weed species greater than 90% in spring-type white lupin [11, 12]. Additionally, metolachlor, alone or mixed with linuron, did not cause white lupin injury [13].

Knott [8] found that lupin are especially sensitive to postemergent (POST) herbicides. Fluazifop, as a POST application, provided ≥98% control of wheat (*Triticum aestivum* L.), triticale (x Triticosecale Wittm ex A. Camus), and annual ryegrass (*Lolium multiflorum* Lam.) without causing injury to the lupin crop [8, 14]. POST application of imazethapyr provided good weed control but resulted in 15% to 24% crop injury and yield reduction [13]. Similarly, Penner et al. [12] found that the use of imazethapyr, as either PRE or POST, caused crop damage of 35% to 60%. Hashem et al. [15] showed that interrow weed control in narrow-leaf lupin provided by paraquat plus diquat increased yields compared to glyphosate alone, glyphosate plus metribuzin, and glyphosate followed by paraquat plus diquat.

Currently, only three herbicides are registered for use in lupin: S-metolachlor, carfentrazone-ethyl, and glyphosate [16]. Therefore, the objective of this experiment is to investigate the use of chemical weed management practices in white lupin and evaluate their effect on weed control, crop injury, and lupin grain yield.

### 2. Materials and methods

**Experimental treatment and design.** A two-year experiment 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. The experiment was a 2 (year) x 2 (location) x 3 (cultivar) x 4 (block) x 24 (weed control) factorial treatment arrangement. The experiment
design was a randomized complete block design (r = 4) nested within each year x location x cultivar combination. The weed control factor had 20 levels: one nontreated control, ten PRE-applied herbicides, and nine POST-applied herbicides (Table 1). 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 soil; a coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults with a loamy sand surface structure. At PBU, the experiment was conducted on a Compass Soil: 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 (a low-alkaloid, determinate grain type experimental cultivar).

| Treatment                      | Class | Rate     | Unit      |
|--------------------------------|-------|----------|-----------|
| None                           |       |          |           |
| S-metolachlor + Linuron        | PRE   | 1.12 + 1.12 | kg ai ha⁻¹ |
| Metribuzin                     | PRE   | 0.42     | kg ai ha⁻¹ |
| Linuron                        | PRE   | 1.12     | kg ai ha⁻¹ |
| S-metolachlor                  | PRE   | 1.12     | kg ai ha⁻¹ |
| Pendimethalin (0.5 X)          | PRE   | 0.84     | kg ai ha⁻¹ |
| Pendimethalin (1 X)            | PRE   | 1.68     | kg ai ha⁻¹ |
| Pendimethalin (2 X)            | PRE   | 3.36     | kg ai ha⁻¹ |
| Diclosulam                     | PRE   | 0.026    | kg ai ha⁻¹ |
| Flumioxazin                    | PRE   | 0.071    | kg ai ha⁻¹ |
| Imazethapyr                    | PRE   | 0.071    | kg ai ha⁻¹ |
| Thifensulfuron (2007)          | POST  | 0.071    | kg ai ha⁻¹ |
| Carfentrazone (2008)           | PDS   | 46.8     | g product ha⁻¹ |
| Fluazifop                      | POST  | 0.84     | kg ai ha⁻¹ |
| Fomesafen                      | POST  | 0.28     | kg ai ha⁻¹ |
| 2,4-DB                         | POST  | 0.28     | kg ai ha⁻¹ |
| Chlorimuron (2007)             | POST  | 0.052    | kg ai ha⁻¹ |
| Clove/Cinnamon Oil (2008)      | PDS   | 6.9      | L product ha⁻¹ |
| Glyphosate                      | PDS   | 1.12     | kg ai ha⁻¹ |
| Sethoxydim                     | POST  | 0.28     | kg ai ha⁻¹ |
| Flumioxazin                    | PDS   | 0.071    | kg ai ha⁻¹ |
| Imazethapyr                    | POST  | 0.071    | kg ai ha⁻¹ |

Table 1. Herbicide treatments, timing, and rates for 2007 and 2008 at the Field Crops Unit and Plant Breeding Unit at E.V. Smith Research Center.
Crop management. Inoculated lupin was seeded in four-row plots with a John Deer 1700 four-row vacuum planter\(^1\) 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\(^{-1}\). 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 four-row ripper/bedder\(^2\) due to concerns about potential saturated soil conditions 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 rainfall) weeks after planting.

Ratings. Weed control ratings were recorded at both locations on a scale from 0% (no weed control) to 100% (complete weed control). The nontreated control was used to estimate the level of control in the treated plots. Two weed control ratings per treatment/plot were taken in each study year. The first rating was taken six weeks after planting and PRE application in both years. The second rating was taken 22 and 26 weeks after planting in 2007/2008 and 2008/2009, respectively.

Crop injury ratings were taken on a scale from 0 (no injury/alive) to 10 (complete injury/dead). The nontreated control was considered to have 0 crop injury. In 2007/2008, crop injury ratings were taken three weeks after planting and PRE application and 15 weeks after planting. In 2008/2009, injury ratings were taken four weeks after planting and PRE application and 18 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 attaining maturity. The two center rows of each plot were harvested with a 2-row/10 ft Massey Ferguson plot combine\(^3\) to determine grain yield (kg ha\(^{-1}\)).

Statistical analysis. We used generalized linear mixed models procedures as implemented in SAS\(^4\) PROC GLIMMIX to analyze weed control data. This tool is flexible in the analysis of data with nonnormal distribution and unbalanced designs. Violations of normality and homogeneity of variance issues are often encountered when including a nontreated control treatment or percent control data with a large range. Weed control data were modelled using a binary distribution function or arcsine transformed data. Crop injury data were modelled using arcsine transformed data and then analyzed with a normal distribution function. All treatment factors and their interactions were considered fixed effects except the block factor and its interaction with the various treatment factors. Statistical significance was declared at Dunnett’s P < 0.1.

3. Results and discussion

Weed control. Over the course of the two-year study, 14 weed species were observed. Not all species were present in all environments; therefore, weed control is presented for only those species that appear at both sites in each year of the study. At the first rating after planting, in both years, the following PRE herbicides provided greater than 90% control of all rated weed species when compared to the nontreated included: \(S\)-metolachlor\(^5\)/linuron\(^6\) mixture, metri-
buzin\textsuperscript{7}, diclosulam\textsuperscript{8}, flumioxazin\textsuperscript{9}, and imazethapyr\textsuperscript{10} (Table 2). Linuron and S-metolachlor alone provided greater than 90% control in most instances except for henbit (\textit{Lamium amplexicaule} L.), which was controlled by linuron at 86%, as well as lesser swinecress \textit{[Coronopus didymus} (L.) Sm.] and heartwing sorrel (\textit{Rumex hastatulus} Baldw.), which were controlled by S-metolachlor at 86% and 88%, respectively (Table 2). The mixture of S-metolachlor/linuron has been used previously in lupin study, even though linuron is not labeled for use in white lupin production in the southeastern US \cite{17, 18}. In this study, at both early weed and late weed ratings, this mixture provided greater than 70% control of all rated weed species.

Pendimethalin\textsuperscript{11} provided good early season control of all weed species at the 0.5X, 1X, and 2X rate with the exception of lesser swinecress and heartwing sorrel, which were controlled less than 50% by the 0.5X and 1X rates.

| Treatment                  | Annual bluegrass | Corn spurry | Heartwing sorrel | Henbit | Lesser swinecress |
|----------------------------|------------------|-------------|------------------|--------|------------------|
| Name                       | Class            | 2008        | 2007             | 2008   | 2007             | 2008   | 2008             |
| None                       | Control          | 5           | 35               | 4      | 4                | 22     | 1                | 3      |
| S-metolachlor/LinuronPRE   | PRE              | 94          | 99               | 99     | 94               | 99     | 92               | 93     |
| Metribuzin                 | PRE              | 96          | 99               | 96     | 98               | 97     | 97               | 96     |
| Linuron                    | PRE              | 98          | 99               | 99     | 92               | 95     | 96               | 86     |
| S-metolachlor              | PRE              | 95          | 98               | 76     | 88               | 90     | 98               | 86     |
| Pendimethalin (0.5X)       | PRE              | 86          | 98               | 97     | 48               | 97     | 99               | 45     |
| Pendimethalin (1X)         | PRE              | 89          | 94               | 94     | 46               | 99     | 97               | 41     |
| Pendimethalin (2X)         | PRE              | 93          | 98               | 98     | 79               | 99     | 98               | 78     |
| Diclosulam                 | PRE              | 97          | 99               | 95     | 98               | 99     | 98               | 98     |
| Flumioxazin                | PRE              | 97          | 99               | 99     | 98               | 99     | 99               | 99     |
| Imazethapyr                | PRE              | 90          | 98               | 90     | 97               | 93     | 99               | 95     |

* All means were significantly different from the control plot using the Dunnett’s test with $P < 0.1$.

Table 2. Mean weed control ratings for 2007 and 2008 six weeks after lupin planting (prior to postemergence herbicide applications) at the Plant Breeding Unit at E.V. Smith Research Center, Tallassee, AL.*

In 2007, the second weed rating (22 weeks after planting) conducted after POST herbicide applications revealed PRE applied herbicide weed control to be greater than nontreated controls at both FCU and PBU for each rated weed species except for cutleaf evening-primrose (\textit{Oenothera laciniata} Hill). At PBU, pendimethalin (0.5X rate) provided only 14% weed control and at FCU, cutleaf evening-primrose control was only 23% with the 1X rate of pendimethalin (Table 3). Less than 50% control was achieved for this weed species with the 2X rate of pendimethalin as well as S-metolachlor. The following POST applied herbicides provided greater than 50% control of all rated weed species included: fluazifop\textsuperscript{12}, chlorimuron\textsuperscript{13}, and
imazethapyr. With the exception of black medic (*Medicago lupulina* L.) and crimson clover (*Trifolium incarnatum* L.), which were controlled by less than 70% (data not shown), imazethapyr controlled all broadleaf weed species by more than 80%. Ivany and McCully [13] evaluated various herbicides for use in sweet white lupin, they also showed that imazethapyr applied PRE and POST provided good broadleaf weed control (80% to 91%). Sethoxydim\textsuperscript{14} provided good control for all weed species except for cutleaf evening-primrose, which was less than 50% at both sites. The grass weed species, annual bluegrass (*Poa annua* L.), was successfully controlled by the POST-applied grass active herbicides sethoxydim and fluazifop which is in agreement with previous research evaluating grass control in lupin [14, 19]. Thifensulfuron\textsuperscript{15} did not provide greater weed control than the nontreated for cutleaf evening-primrose at FCU (15%) and provided less than 50% control of this species at PBU (31%) as well as corn spurry (*Spergula arvensis* L.) at FCU (43%) (Table 3). Corn spurry control was also less than 50% for fomesafen\textsuperscript{16} at both FCU (22%) and PBU (37%) and 2,4-DB at FCU (39%). Glyphosate\textsuperscript{17} and flumioxazin, which were both POST-directed spray applications, provided good weed control of all rated weeds at both locations (Table 3).

| Treatment                      | Annual bluegrass | Corn spurry | Cutleaf evening-primrose | Shepherd’s purse | Winter vetch |
|--------------------------------|------------------|-------------|---------------------------|------------------|-------------|
|                                | FCU   | PBU | FCU   | PBU | FCU   | PBU | FCU   | PBU | FCU   | PBU | FCU   | PBU |
| None                           | Control | 0   | 0     | 0     | 0     | 2   | 0     | 3   | 0     | 6   | 0     |     |
| S-metolachlor/ Linuron         | PRE   | 98  | 97    | 98    | 99    | 92  | <0.0001 | 95  | <0.0001 | 98  | 99    | 97  |
| Metribuzin                     | PRE   | 98  | 78    | 96    | 86    | 94  | <0.0001 | 91  | <0.0001 | 99  | 99    | 89  | 81 |
| Linuron                        | PRE   | 96  | 90    | 97    | 99    | 70  | <0.0001 | 83  | <0.0001 | 98  | 99    | 94  | 72 |
| S-metolachlor                  | PRE   | 98  | 93    | 99    | 99    | 45  | 0.0015  | 36  | 0.0007  | 97  | 95    | 96  | 66 |
| Pendimethalin (0.5X)           | PRE   | 98  | 58    | 99    | 99    | 42  | 0.0031  | 14  | 0.5624  | 97  | 90    | 95  | 86 |
| Pendimethalin (1X)             | PRE   | 98  | 92    | 99    | 99    | 23  | 0.1595  | 28  | 0.0089  | 99  | 96    | 95  | 61 |
| Pendimethalin (2X)             | PRE   | 99  | 82    | 99    | 99    | 39  | 0.0065  | 48  | 0.0003  | 99  | 99    | 98  | 73 |
| Diclosulam                     | PRE   | 95  | 68    | 88    | 97    | 96  | <0.0001 | 94  | <0.0001 | 99  | 99    | 99  | 97 |
| Flumioxazin                    | PRE   | 98  | 80    | 99    | 99    | 97  | <0.0001 | 95  | <0.0001 | 99  | 99    | 83  | 74 |
| Imazethapyr                    | PRE   | 97  | 87    | 88    | 97    | 85  | <0.0001 | 92  | <0.0001 | 89  | 97    | 79  | 60 |
| Thifensulfuron POST            | 98    | 64  | 43    | 98    | 15    | 0.5624 | 31  | 0.0005  | 98  | 99    | 98  | 89 |
| Fluazifop                      | POST  | 97  | 99    | 80    | 65    | 57  | 0.0001  | 50  | <0.0001 | 98  | 95    | 94  | 57 |
TABLE 3. Mean weed control ratings 22 weeks after lupin planting in 2007 at the Plant Breeding Unit (PBU) and the Field Crops Unit (FCU) at E.V. Smith Research Center, Tallassee, AL.

| Treatment  | Annual bluegrass | Corn spurry | Cutleaf evening-primrose | Shepherd’s purse | Winter vetch |
|------------|------------------|-------------|--------------------------|------------------|-------------|
| Fomesafen  | POST             | 94          | 67                       | 22               | 37          |
|            |                  |             |                          | 59               | <0.0001     |
|            |                  |             |                          | 70               | <0.0001     |
| 2,4-DB     | POST             | 93          | 76                       | 39               | 60          |
|            |                  |             |                          | 98               | <0.0001     |
|            |                  |             |                          | 99               | <0.0001     |
| Chlorimuron| POST             | 99          | 65                       | 93               | 98          |
|            |                  |             |                          | 98               | <0.0001     |
|            |                  |             |                          | 98               | <0.0001     |
| Glyphosate | PDS              | 98          | 89                       | 88               | 92          |
|            |                  |             |                          | 69               | <0.0001     |
|            |                  |             |                          | 83               | <0.0001     |
| Sethoxydim | POST             | 97          | 96                       | 71               | 84          |
|            |                  |             |                          | 45               | 0.0014      |
|            |                  |             |                          | 45               | 0.0002      |
|            |                  |             |                          | 97               | 91          |
|            |                  |             |                          | 93               | 53          |
| Flumioxazin| PDS              | 95          | 80                       | 98               | 93          |
|            |                  |             |                          | 93               | <0.0001     |
|            |                  |             |                          | 88               | <0.0001     |
|            |                  |             |                          | 98               | 91          |
|            |                  |             |                          | 95               | 79          |
| Imazethapyr| POST             | 97          | 77                       | 86               | 88          |
|            |                  |             |                          | 81               | <0.0001     |
|            |                  |             |                          | 85               | <0.0001     |
|            |                  |             |                          | 98               | 96          |
|            |                  |             |                          | 91               | 65          |

'S Denotes means within location that are all significantly different from control using Dunnett’s test with P-value <0.1.
| Treatment | Corn spurry | Cutleaf evening-primrose | Wild radish | Winter vetch |
|-----------|-------------|--------------------------|-------------|--------------|
|           | FCU  | PBU | FCU  | PBU | FCU  | PBU | FCU  | PBU | FCU  | PBU |
| Name      | Class       | Mean | Dunnett’s Mean P-value | Mean | Dunnett’s Mean P-value | Mean | Dunnett’s Mean P-value | Mean | Dunnett’s Mean* P-value | Mean* | Mean* |
| None      | Control     | 0    | 0   | 0   | 0   | 0   | 2   | 0   | 0   |      |
| S-metolachlor/ PRE | 94 | <0.0001 | 97 | <0.0001 | 77 | <0.0001 | 72 | <0.0001 | 92 | <0.0001 | 98 | 99 | 96 |
| Metribuzin | PRE | 74 | <0.0001 | 85 | <0.0001 | 73 | <0.0001 | 61 | <0.0001 | 91 | 98 | 67 |
| Linuron | PRE | 83 | <0.0001 | 85 | <0.0001 | 75 | <0.0001 | 75 | <0.0001 | 98 | <0.0001 | 93 | 99 | 76 |
| S-metolachlor | PRE | 57 | <0.0001 | 63 | <0.0001 | 30 | 0.0182 | 12 | 0.1984 | 42 | 0.0651 | 80 | 94 | 85 |
| Pendimethalin | PRE | 78 | <0.0001 | 96 | <0.0001 | 10 | 0.5673 | 12 | 0.1746 | 3 | 0.9999 | 63 | 97 | 46 |
| (0.5X) | Pendimethalin | PRE | 90 | <0.0001 | 92 | <0.0001 | 23 | 0.0681 | 6 | 0.6044 | 21 | 0.3890 | 93 | 96 | 92 |
| (1X) | Pendimethalin | PRE | 91 | <0.0001 | 96 | <0.0001 | 18 | 0.1434 | 8 | 0.4548 | 84 | 0.0051 | 96 | 99 | 83 |
| (2X) | Diclosulam | PRE | 79 | <0.0001 | 91 | <0.0001 | 85 | <0.0001 | 91 | <0.0001 | 99 | <0.0001 | 98 | 99 | 88 |
| Flumioxazin | PRE | 94 | <0.0001 | 98 | <0.0001 | 94 | <0.0001 | 95 | <0.0001 | 98 | <0.0001 | 96 | 98 | 90 |
| Imazethapyr | PRE | 42 | 0.0003 | 97 | <0.0001 | 48 | 0.0003 | 96 | <0.0001 | 85 | 0.0002 | 95 | 99 | 49 |
| Carfentrazone | POST | 23 | 0.0292 | 55 | 0.0001 | 62 | <0.0001 | 35 | 0.0007 | 69 | 0.0028 | 74 | 96 | 70 |
| Fluazifop | POST | 7 | 0.6489 | 6 | 0.8047 | 66 | <0.0001 | 28 | 0.0041 | 32 | 0.1578 | 43 | 90 | 82 |
| Fomesafen | POST | 14 | 0.1718 | 19 | 0.1242 | 41 | 0.0018 | 75 | <0.0001 | 94 | <0.0001 | 99 | 99 | 77 |
| 2,4-DB | POST | 6 | 0.7628 | 5 | 0.9214 | 82 | <0.0001 | 96 | <0.0001 | 21 | 0.3932 | 63 | 98 | 73 |
| Clove/ | POST | 26 | 0.0160 | 32 | 0.0124 | 58 | <0.0001 | 14 | 0.1984 | 29 | 0.2074 | 99 | 99 | 51 |
| Cinnamon Oil | | | | | | | | | | | | | |
| Glyphosate | POST | 94 | <0.0001 | 98 | <0.0001 | 95 | <0.0001 | 91 | <0.0001 | 96 | <0.0001 | 57 | 97 | 94 |
| Sethoxylid | POST | 7 | 0.6549 | 45 | 0.0010 | 39 | 0.0028 | 25 | 0.0091 | 36 | 0.1083 | 83 | 95 | 54 |
| Flumioxazin | POST | 80 | <0.0001 | 81 | <0.0001 | 81 | <0.0001 | 68 | <0.0001 | 60 | 0.0082 | 72 | 97 | 80 |
| Imazethapyr | POST | 34 | <0.0001 | 96 | <0.0001 | 82 | <0.0001 | 96 | <0.0001 | 97 | <0.0001 | 71 | 99 | 68 |

* Denotes means within location that are all significantly different from control using Dunnett’s test with P-value < 0.1.

Table 4. Mean weed control ratings 26 weeks after lupin planting in 2008 at the Plant Breeding Unit (PBU) and the Field Crops Unit (FCU) at E.V. Smith Research Center, Tallassee, AL.
(9.43 to 10.00), regardless of cultivar or location; therefore, they were discontinued in 2008 (Table 5). Thifensulfuron and chlorimuron were initially included in this study since they are registered for use in soybean; however, research has shown variable phytotoxicity among soybean cultivars for both herbicides [21, 22]. Research conducted by Knott [8] suggests that sulfonylurea herbicides such as metsulfuron cause variable crop injury in white lupin, ranging from limited to severe when applied at the normal field rate. Flumioxazin, as a POST-directed spray, caused significant crop injury at each location for each cultivar (4.50 to 7.84). Significant injury resulted from the use of fomesafen at FCU regardless of cultivar; however, increased injury was not observed with this herbicide at PBU. Glyphosate also resulted in increased lupin injury at FCU for ABL 1082 (6.30) and AU Alpha (5.89) (Table 5). Glyphosate is registered for POST-directed application in lupin in the US [16]; however, herbicide drift can easily cause significant crop injury. This was the most likely cause of lupin injury in our study. Injury from POST flumioxazin applications may also be attributed to drift since PRE applications of this herbicide did not result in increased crop injury in most cases; although, in drier soil conditions, increased phytotoxicity of flumioxazin has been observed in other crops. This could pose a risk for increased lupin damage [23]. Fluazifop (0.50 to 3.81), 2,4-DB (0.06 to 0.75), sethoxydim (0.26 to 2.28), and imazethapyr (0.94 to 4.45) did not result in increased lupin injury over the nontreated (Table 5).

Crop injury in 2008 resulted in less overall lupin injury than in 2007. PRE applied herbicides did not cause significant injury in comparison to a nontreated at either location for any of the cultivars except for diclosulam (5.26 to 9.00), which caused unacceptable injury, regardless of location or cultivar (Table 6). Diclosulam, which is applied either preplant incorporated (PPI) or PRE, is registered in soybean (Glycine max (L.) Merr.) and peanut (Arachis hypogaea L.) with little injury to either crop [24, 25]. Lupin injury from PRE applications of diclosulam was significant for each cultivar included in the experiment. POST-applied herbicides did not increase crop injury over nontreated except for glyphosate (4.49 to 7.76) and fomesafen in AU Alpha at both locations (3.22 to 3.48) and in AU Homer at PBU (4.00) (Table 6). Crop injury from fomesafen was noted in both years of the study with inconsistent injury for each cultivar. In other crops, such as soybean and dry beans, previous research has reported negligible fomesafen injury regardless of cultivar [26, 27]. In this study, however, it is evident that fomesafen can produce significant injury to lupin.

**Grain yield.** Mean grain yields (kg ha⁻¹) were much higher for all three cultivars in 2008 as compared to 2007 (Table 7). 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 nontreated had a mean grain 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 7). Two POST-applied herbicides, thifensulfuron and chlorimuron, had no measurable yields in 2007. In 2008, glyphosate was the only POST-applied herbicide that caused significant yield losses of 1700 kg ha⁻¹.
| Treatment                  | ABL 1082 FCU | ABL 1082 PBU | AU Alpha FCU | AU Alpha PBU | AU Homer FCU | AU Homer PBU |
|----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Name                       |              |              |              |              |              |              |
| Class                      |              |              |              |              |              |              |
| Mean crop injury           |              |              |              |              |              |              |
| Dunnett's Mean              |              |              |              |              |              |              |
| P-value                    |              |              |              |              |              |              |
| Mean crop injury           |              |              |              |              |              |              |
| Dunnett's Mean              |              |              |              |              |              |              |
| P-value                    |              |              |              |              |              |              |
| Mean crop injury           |              |              |              |              |              |              |
| Dunnett's Mean              |              |              |              |              |              |              |
| P-value                    |              |              |              |              |              |              |
| Mean crop injury           |              |              |              |              |              |              |
| Dunnett's Mean              |              |              |              |              |              |              |
| P-value                    |              |              |              |              |              |              |
| None                       | 1.49         | 0.91         | 0.21         | 1.68         | 0.57         | 1.06         |
| S-metolachlor/ PRE         | 0.38         | 0.8758       | 2.16         | 0.9490       | 1.68         | 0.4758       |
| Linuron                    |              |              |              |              |              |              |
| Metribuzin PRE             | 1.85         | 1.0000       | 1.95         | 0.9891       | 4.45*        | 0.0011       |
| Linuron                    | 0.88         | 1.0000       | 2.40         | 0.8482       | 0.75         | 0.9980       |
| Pendimethalin PRE          | 2.05         | 1.0000       | 1.22         | 1.0000       | 1.04         | 0.9355       |
| (0.5X)                     | 2.32         | 0.9999       | 1.22         | 1.0000       | 0.38         | 1.0000       |
| Pendimethalin PRE          | 1.99         | 1.0000       | 0.53         | 1.0000       | 0.57         | 1.0000       |
| (1X)                       | 2.88         | 0.9652       | 1.46         | 1.0000       | 3.95*        | 0.0042       |
| Pendimethalin PRE          |              |              |              |              |              |              |
| (2X)                       |              |              |              |              |              |              |
| Diclosulam PRE             | 9.06*        | <0.0001      | 6.05*        | 0.0311       | 9.94*        | <0.0001      |
| Flumioxazin PRE            | 1.56         | 1.0000       | 0.26         | 0.9934       | 2.86*        | 0.0555       |
| Imazethapyr PRE            | 2.15         | 1.0000       | 1.46         | 1.0000       | 2.08         | 0.2500       |
| Thifensulfuron/POST         | 10.00*       | <0.0001      | 10.00*       | <0.0001      | 9.52*        | <0.0001      |
| Fluazifop POST             | 3.81         | 0.5138       | 1.68         | 0.9997       | 0.50         | 1.0000       |
| Fomesafen POST             | 8.00*        | <0.0001      | 2.40         | 0.8482       | 6.78*        | <0.0001      |
| 2,4-DB POST                | 0.50         | 0.9631       | 0.75         | 1.0000       | 0.57         | 1.0000       |
| Chlorimuron POST           | 9.94*        | <0.0001      | 9.94*        | <0.0001      | 9.99*        | <0.0001      |
| Glyphosate PDS             | 6.30*        | 0.0060       | 2.71         | 0.6636       | 5.89*        | <0.0001      |
| Sethoxydim POST            | 2.28         | 1.0000       | 3.81         | 0.1551       | 0.26         | 1.0000       |
| Flumioxazin PDS            | 7.29*        | 0.0003       | 4.50*        | 0.0452       | 7.84*        | <0.0001      |
| Imazethapyr POST           | 4.45         | 0.2304       | 0.94         | 1.0000       | 1.06         | 0.9242       |

* Denotes mean crop injury significantly different from control within location using Dunnett’s P-value <0.1.

Table 5. Mean crop injury ratings 15 weeks after planting in 2007 at the Plant Breeding Unit (PBU) and the Field Crops Unit (FCU) at E.V. Smith Research Center, Tallassee, AL.
| Treatment | AU Alpha | AU Homer |
|-----------|----------|----------|
|           | FCU PBU  | FCU PBU  | FCU PBU  | FCU PBU  | FCU PBU  | FCU PBU  |
| Name      | Class    | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value | Mean crop injury | Dunnett’s Mean crop injury P-value |
| None      | Control  | 0.75      | 1.72      | 0.8164   | 0.57     | 1.00     | 1.90     | 1.46     | 1.00     |
| S-metolachlor | PRE | 1.00      | 1.0000    | 3.09     | 0.9999   | 0.57     | 0.9999   | 1.95     | 1.0000   | 1.22     | 1.0000   |
| Linuron   |          |           |           |          |          |          |          |          |          |
| Metribuzin| PRE      | 2.40      | 0.3071    | 1.72     | 1.0000   | 0.26     | 0.9999   | 0.53     | 0.4054   | 1.00     | 1.0000   |
| Linuron   |           | 0.26      | 0.9871    | 1.22     | 1.0000   | 0.06     | 0.8164   | 0.75     | 0.7267   | 1.46     | 1.0000   |
| S-metolachlor | PRE | 1.88      | 0.7463    | 1.22     | 1.0000   | 1.22     | 0.9871   | 0.2778   | 1.95     | 1.0000   | 0.57     | 0.8730   |
| Pendimethalin | PRE | 0.53      | 1.0000    | 0.94     | 0.9871   | 0.38     | 0.9999   | 0.06*    | 0.0120   | 1.22     | 1.0000   |
| (0.5X)     |          |           |           |          |          |          |          |          |          |          |          |
| Pendimethalin | PRE | 0.53      | 1.0000    | 1.72     | 1.0000   | 1.06     | 0.9994   | 0.38     | 0.9716   | 0.26     | 0.1031   | 1.00     | 1.0000   |
| (1X)       |          |           |           |          |          |          |          |          |          |          |          |          |
| Pendimethalin | PRE | 0.91      | 1.0000    | 2.11     | 1.0000   | 0.57     | 1.0000   | 1.00     | 1.0000   | 0.38     | 0.2178   | 1.00     | 1.0000   |
| (2X)       |          |           |           |          |          |          |          |          |          |          |          |          |
| Diclosulam | PRE      | 8.78*     | <0.0001   | 5.26*    | 0.0080   | 9.00*    | <0.0001  | 9.00*    | <0.0001  | 7.60*    | <0.0001  | 7.26*    | <0.0001  |
| Flumioxazin| PRE      | 0.75      | 1.0000    | 6.28*    | 0.0002   | 0.57     | 1.0000   | 2.51     | 0.5138   | 0.38     | 0.2178   | 1.68     | 1.0000   |
| Imazethapyr| PRE      | 0.57      | 1.0000    | 2.51     | 0.9966   | 0.26     | 0.9999   | 1.22     | 1.0000   | 1.46     | 1.0000   | 1.00     | 1.0000   |
| Carfentrazone | PDS | 0.94      | 1.0000    | 1.22     | 1.0000   | 1.46     | 0.8730   | 0.57     | 0.9999   | 1.12     | 0.9932   | 1.72     | 1.0000   |
| Fluazifop  | POST     | 1.72      | 0.8730    | 1.46     | 1.0000   | 1.46     | 0.8730   | 1.22     | 1.0000   | 0.75     | 0.7267   | 1.22     | 1.0000   |
| Fomesafen  | POST     | 2.66      | 0.1776    | 3.22     | 0.7188   | 3.22*    | 0.0155   | 3.48*    | 0.0648   | 2.11     | 1.0000   | 4.00*    | 0.0981   |
| 2,4-DB     | POST     | 1.00      | 1.0000    | 2.40     | 0.9998   | 0.38     | 1.0000   | 0.26     | 0.8164   | 0.06*    | 0.0120   | 1.00     | 1.0000   |
| Clove/     | PDS      | 0.57      | 1.0000    | 2.40     | 0.9998   | 0.06     | 0.8164   | 1.00     | 1.0000   | 0.75     | 0.7267   | 1.22     | 1.0000   |
| Cinnamon Oil |          |           |           |          |          |          |          |          |          |          |          |          |

* Denotes mean crop injury significantly different from control within location using Dunnett’s P-value <0.1.

**Table 6.** Mean crop injury ratings 18 weeks after planting in 2008 at the Plant Breeding Unit (PBU) and the Field Crops Unit (FCU) at E.V. Smith Research Center, Tallassee, AL.
| Treatment | ABL 1082 | AU Alpha | AU Homer | ABL 1082 | AU Alpha | AU Homer |
|-----------|----------|----------|----------|----------|----------|----------|
| Name | Class | Mean | Dunnett’s Mean* | Mean* | Mean | Dunnett’s Mean | Dunnett’s Mean | Dunnett’s Mean | Dunnett’s Mean |
| None | Control | 1337 | 702 | 555 | 2074 | 1957 | 1219 |
| S-metolachlor/ Linuron | PRE | 1331 | 734 | 877 | 1936 | 1108 | 0.0011 | 1262 | 1.0000 |
| Metribuzin | PRE | 1174 | 778 | 551 | 1612 | 1410 | 0.1150 | 1368 | 0.9315 |
| Linuron | PRE | 1370 | 700 | 729 | 2126 | 1484 | 0.2526 | 1359 | 1.0000 |
| S-metolachlor | PRE | 1176 | 825 | 671 | 1910 | 1108 | 0.0011 | 1262 | 1.0000 |
| Pendimethalin (0.5X) | PRE | 1353 | 664 | 740 | 1937 | 1567 | 0.5104 | 1522 | 0.7994 |
| Pendimethalin (1X) | PRE | 1256 | 767 | 617 | 2025 | 1504 | 0.3048 | 1233 | 1.0000 |
| Pendimethalin (2X) | PRE | 1294 | 719 | 585 | 1907 | 1460 | 0.1984 | 1217 | 1.0000 |
| Diclosulam | PRE | 391 | <0.0001 | 383 | 648 | <0.0001 | 210 | <0.0001 | 548 | 0.0667 |
| Flumioxazin | PRE | 1305 | 594 | 674 | 1470 | 1264 | 0.0159 | 1217 | 1.0000 |
| Imazethapyr | PRE | 1323 | 632 | 630 | 1742 | 1460 | 0.1984 | 1309 | 1.0000 |
| Thifensulfuron (2007) | POST | 0 | <0.0001 | 218 | 177 | ---- | ---- | ---- | ---- |
| Carfentrazone (2008) | POST | ---- | ---- | ---- | ---- | 2081 | 1877 | 1.0000 | 1203 | 1.0000 |
| Fluazifop | POST | 1094 | 0.6993 | 893 | 536 | 1889 | 1827 | 1.0000 | 1573 | 0.7980 |
| Fomesafen | POST | 1167 | 0.9744 | 666 | 666 | 1738 | 1511 | 0.3234 | 1372 | 0.9390 |
| 2,4-DB | POST | 1216 | 0.9996 | 892 | 783 | 2180 | 1321 | 0.0364 | 1580 | 0.7716 |
| Chlorimuron (2007) | POST | 0 | <0.0001 | 0 | 143 | ---- | ---- | ---- | ---- |
| Clove/cinnamon oil (2008) | POST | ---- | ---- | ---- | ---- | 2195 | 1618 | 0.7065 | 1347 | 1.0000 |
| Glyphosate | PDS | 971 | 0.1563 | 673 | 634 | 364 | <0.0001 | 735 | <0.0001 | 839 | 0.3234 |
| Sethoxydim | POST | 1261 | 1.0000 | 706 | 525 | 1941 | 1309 | 0.0309 | 1313 | 1.0000 |
| Flumioxazin | PDS | 1229 | 0.9999 | 597 | 652 | 1938 | 1350 | 0.0545 | 1153 | 1.0000 |
| Imazethapyr | POST | 1317 | 1.0000 | 557 | 695 | 2020 | 1226 | 0.0087 | 1433 | 0.9770 |

* Denotes mean grain yield not significantly different from control within cultivar using Dunnett’s P-value <0.1.

Table 7. Mean grain yield (kg ha\(^{-1}\)) for 2007 and 2008 at E.V. Smith Research Center, Tallassee, AL averaged across location.
**AU Alpha.** Mean grain yields of 702 kg ha\(^{-1}\) in 2007 and 1957 kg ha\(^{-1}\) were obtained in the nontreated (Table 7). In 2007, none of the PRE- and POST-applied herbicides 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 grain yield of this cultivar. Similarly, glyphosate, with a mean grain yield 735 kg ha\(^{-1}\), was the only POST herbicide that caused significant yield reduction in 2008.

**AU Homer.** The nontreated control had a mean grain yield of 555 kg ha\(^{-1}\) in 2007 and 1219 kg ha\(^{-1}\) in 2008 (Table 7). None of the PRE and POST herbicide treatments significantly reduced or increased yield as compared to the control in 2007. In 2008, none of the PRE or POST herbicide applications, with the exception of PRE diclosulam (548 kg ha\(^{-1}\)), yielded lower than the nontreated control.

Experiments conducted by Payne et al. [4] in the Pacific Northwest showed a maximum white lupin yield of 2128 kg ha\(^{-1}\), but this yield is not stable. In our study, yield within each cultivar varied greatly between years depending on the treatment. The grain-type cultivar ABL 1082 had the highest mean grain yield, followed by the forage-type cultivar AU Alpha and the cover-crop-type cultivar AU Homer. In this experiment, diclosulam, thifensulfuron, chlorimuron, and glyphosate caused major grain yield losses. AU Homer appears to be the least sensitive to herbicide-induced yield reductions, since neither thifensulfuron nor chlorimuron reduced grain yield. Ivany and McCully [13] stated that POST applications of imazethapyr caused severe crop injury and yield loss in sweet white lupin. The results of this study did not confirm their findings. Neither the PRE nor the POST imazethapyr applications caused significant crop injury or subsequent yield reduction. This could be due, in part, to the use of different cultivars than those used by Ivany and McCully [13].

In general, PRE herbicide applications included in this study, excluding diclosulam, could be used in lupin without posing a significant risk of crop injury. Previous observations by Dittman [28] agree with findings that PRE herbicides may cause less lupin injury than POST herbicide options. Certain POST herbicides, such as thifensulfuron, chlorimuron, and fomesafen, are not viable herbicide options for use in lupin. Other POST options, like fluazifop, 2,4-DB, sethoxydim, and imazethapyr, may offer additional options for weed control in lupin without increasing crop injury.

The results of this experiment show that good weed control can be achieved by using a broad spectrum of herbicides that are currently not registered for use in US lupin production such as imazethapyr, flumioxazin, and linuron. With glyphosate and S-metolachlor, which are registered for use in lupin in the US, good weed control in lupin is possible; however, the use of a limited number of active ingredients can potentially increase resistance development in weed species in these systems. Based on these results, it is necessary to expand the number of registered herbicides for use in US lupin production.
4. Sources of materials

1 John Deere 1700 four-row vacuum planter, John Deere, Moline, IL.
2 Four-row ripper/bedder, Kelley Manufacturing Co., Tifton, GA.
3 Two-row Massey Ferguson plot combine, AGCO Corporation, Duluth, GA.
4 Statistical Analysis Systems®, version 9.2, SAS Institute, Inc., Cary, NC.
5 S-metolachlor, Dual Magnum®, Syngenta Crop Protection, Inc., Greensboro, NC.
6 Linuron, Lorox® DF, Tessenderlo Kerley, Inc., Phoenix, AZ.
7 Metribuzin, Sencor®, Bayer CropScience, Research Triangle Park, NC.
8 Diclosulam, Strongarm®, Dow AgroSciences, LLC, Indianapolis, IN.
9 Flumioxazin, Valor®, Valent USA Corporation, Walnut Creek, CA.
10 Imazethapyr, Pursuit®, BASF Corporation, Research Triangle Park, NC.
11 Pendimethalin, Prowl® H2O, BASF Corporation, Research Triangle Park, NC.
12 Fluazifop, Fusilade® DX, Syngenta Crop Protection, Inc., Greensboro, NC.
13 Chlorimuron, DupontTM Classic®, E.I. duPont de Nemours & Company, Wilmington, DE.
14 Sethoxydim, Poast Plus®, BASF Corporation, Research Triangle Park, NC.
15 Thifensulfuron, DupontTM Harmony® SG, E.I. duPont de Nemours & Company, Wilmington, DE.
16 Fomesafen, Reflex®, Syngenta Crop Protection, Inc., Greensboro, NC.
17 Glyphosate, Honcho® Plus, Monsanto Company, St. Louis, MO.
18 Carfentrazone, Aim® EC, FMC Corporation, Philadelphia, PA.
19 Clove/cinnamon oil, Weed ZapTM, JH Biotech, Inc., Ventura, CA.

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References

[1] Clark, M. S., W. R. Horwath, C. Shennan, K. M. Scow, W. T. Lantni and H. Ferris. 1999. Nitrogen, weeds and water as yield-limiting factors in conventional, low-input, and organic tomato systems. *Agri Ecosys Environ* 73: 257-270.

[2] Hill, G. D. 2005. The use of lupin seed in human and animal diets – revisited. In: E. van Santen and G.D. Hill (eds) *Mexico, Where Old and New World Lupins Meet*. Proceedings of the 11th International Lupin Conference, Guadalajara, Jalisco, Mexico. May 4-5, 2005. International Lupin Association, Canterbury, New Zealand, ISBN 0-86476-165-1.

[3] Noffsinger, S. L. and E. van Santen. 2005. Evaluation of *Lupinus albus* L. Germplasm for the Southeastern USA. *Crop Sci* 45:1941-1950.

[4] Payne, W. A., C. Chen and D. A. Ball. 2004. Alternative crops agronomic potential of alternative crops agronomic potential of narrow-leaved and white lupins in the Inland Pacific Northwest. *Agro J* 96:1501-1508.

[5] van Santen, E. and D. W. Reeves. 2003. Tillage and rotation effects on lupin in double-cropping systems in the southeastern USA. In: E. van Santen and G. D. Hill (eds). *Wild and Cultivated Lupins from the Tropics to the Poles*. Proceedings of the 10th International Lupin Conference, Laugarvatn, Iceland, 19-24 June 2002. International Lupin Association, Canterbury, New Zealand. ISBN 0-86476-153-8.

[6] Putnam, D. H., E. S. Oplinger, L. L. Hardman, and J. D. Doll. 1989. *Lupine, Alternative Field Crops Manual*, University of Wisconsin-Extension, Cooperative Extension; University of Minnesota: Center for Alternative Plant and Animal Products and the Minnesota Extension Service. http://www.hort.purdue.edu/newcrop/afcm/lupine.html

[7] Poetsch, J. 2006. Pflanzenbauliche Untersuchungen zum ökologischen Anbau von Körnerleguminosen an sommertrockenen Standorten Südwestdeutschlands, Institut für Pflanzenbau und Grünland der Universität Hohenheim, Salzgitter, PhD-dissertation.

[8] Knott, C. M. 1996. Tolerance of Autumn-sown determinate Lupins (*Lupinus albus*) to herbicides. Test of Agrochemicals and Cultivars 17. *Ann Appl Biol* 128.

[9] Mitich, L. W., K. Cassman and N. L. Smith. 1989. Evaluation of herbicides at three times of application in grain lupine. *Research Progress Report* pp. 313-314.

[10] Ball, D. A. 1992. Weed Control in white lupine. *Research Progress Report*.

[11] Mitich, L. W., K. G. Cassman, K. J. Larson and N. L. Smith. 1987. Evaluation of pre-emergence herbicides for control of winter annual weeds in “Minnesota Ultra” lupins. *Research Progress Report* pp 222-223.
[12] Penner, D., R. H. Leep, F. C. Roggenbuck and J. R. Lempke. 1993. Herbicide efficacy and tolerance in sweet white lupin. *Weed Technol* 7:42-46.

[13] Ivany, J. A. and K. V. McCully. 1994. Evaluation of herbicides for sweet white lupin (*Lupinus albus*). *Weed Technol* 8:819-823.

[14] Chambers, A., G. Code and G. Scammell. 1995. Annual ryegrass and volunteer cereal control in lupins using selective post-emergence herbicides. *Austr J Exper Agri* 35:1141-1149.

[15] Hashem, A., R. M. Collins, and D. G. Bowran. 2011. Efficacy of interrow weed control techniques in wide row narrow-leaf lupin. *Weed Technol* 25:135-140.

[16] Crop Protection Reference (CPR). 2011. 27th edition of Greenbook’s *Crop Protection Reference*. Vance Publishing Corporation. Lenexa, KS.

[17] Noffsinger, S. L. 1998. Physiology and management of winter-type white lupin (*Lupinus albus* L.). Auburn, AL: PhD. Diss. Auburn University.

[18] Noffsinger, S. L., C. Huyghe and E. van Santen. 2000. Analysis of grain-yield components and inflorescence levels in winter-type white lupin. *Agron J* 92:1195-1202.

[19] Fua, J. M. 1981. Weed control in direct-drilled lupins using simazine and post-emergence herbicides in *Lupinus angustifolius*. In: Proceedings of the 6th Australian Weeds Conference. September 13-18 1981. City of Gold Coast, Queensland.

[20] Hardcastle, W. S. 1979. Soybean cultivar response to metribuzin in solution culture. *Weed Sci* 27: 278-279.

[21] Nelson, K. A., K. A. Renner and R. Hammerschmidt. 2002. Cultivar and herbicide selection affects soybean development and the Incidence of Sclerotinia. *Agron J* 94: 1270-1281.

[22] Prostko, E. P., B. A. Majek, and J. Ingerson-Mahar. 1996. The effect of chlorimuron/linuron combinations on soybean (*Glycine max*) growth and yield. *Weed Technol* 10: 519-521.

[23] Taylor-Lovell, S., L. M. Wax, and R. Nelson. 2001. Phytotoxic response and yield of soybean (*Glycine max*) varieties treated with sulfentrazone or flumioxazin. *Weed Technol* 15: 95-102.

[24] Bailey, W. A., J. W. Wilcut, D. L. Jordan, C. W. Swann, and V. B. Langston. 1999. Weed management in peanut (*Arachis hypogaea*) with diclosulam preemergence. *Weed Technol* 13: 450-456.

[25] Reddy, K. N. 2000. Weed control in soybean (*Glycine max*) with cloransulam and diclosulam. *Weed Technol* 14: 293-297.
[26] Higgins, J. M., T. Whitwell, E. C. Murdock, and J. E. Toler. 1988. Recovery of pitted morningglory (Ipomoea lacunosa) and ivyleaf morningglory (Ipomoeae hederacea) following applications of acifluorfen, fomesafen, and lactofen. Weed Sci 36: 345-353.

[27] Wilson, R. G. 2005. Response of dry bean and weeds to fomesafen and fomesafen tank mixtures. Weed Technol 19: 201-206.

[28] Dittman, B. 1999. Chemical weed control in Lupinus Luteus and Lupinus Albus production. In: E. van Santen, M. Wink, S. Weissmann, and P. Roemer (eds). Lupin, an Ancient Crop for the New Millennium. Proceedings of the 9th International Lupin Conference, Klink/Müritz, 20-24 June, 1999; pp. 70-73 International Lupin Association, Canterbury, New Zealand. ISBN 0-86476-123-6.
