WEED CONTROL IN

DIRECT-SEEDED PEA AND LENTIL

A Thesis Submitted to the College of Graduate Studies and Research in Partial

Fulfillment of the Requirements for the Degree of Master of Science in the

Department of Crop Science and Plant Ecology

University of Saskatchewan

Saskatoon

By

Sara Catharine Rigetti

Spring 1998

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ABSTRACT

Direct seeding of pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) crops is increasing in popularity in western Canada. Weed control strategies for these two crops are limited in a conventional tillage system; in a direct-seeding system, weed control options become even fewer. The herbicide ethalfluralin is commonly used for weed control in pea sown in a conventional tillage system, but it is not registered for use in direct-seeding systems. Surface application or shallow incorporation of ethalfluralin and triallate/trifluralin (10:4) could offer broad spectrum weed control in direct seeded pea and lentil. The level of weed control, crop tolerance and the economic suitability of the use of the dinitroanilines in direct-seeded pea and lentil was assessed. Results of experiments conducted at two locations near Saskatoon in 1995 and 1996 indicate that surface applications of ethalfluralin and triallate/trifluralin (10:4) offer similar and acceptable grassy weed control. However, ethalfluralin surface applied at rates less than 1.4 kg ai ha^{-1} did not provide acceptable control of wild oat when the wild oat population was high. Ethalfluralin applied in combination with a spring glyphosate burn-off treatment, followed by post-emergent metribuzin in lentil and MCPA-Na salt in pea, resulted in better broadleaf weed control than ethalfluralin applied in combination with fall-applied metribuzin. Post-emergent broadleaf weed control options were also more economical than fall-applied weed control options. Pea and lentil tolerance to reduced incorporation of ethalfluralin and triallate/trifluralin (10:4) was excellent. Glyphosate did not interfere with nitrogen fixation in either pea or lentil. The use of ethalfluralin and triallate/trifluralin (10:4), in combination with glyphosate applied in the spring and a

post-emergent application of metribuzin in lentil and MCPA-Na salt in pea, has potential for broad spectrum weed control in direct-seeded pea and lentil in western Canada.

ACKNOWLEDGEMENTS

I wish to express my thanks to my supervisor, F.A. Holm, for his advice and guidance throughout the study. Thanks also go to my committee members, A.E. Slinkard, C. van Kessel, J.J. Schoenau, and M.D. Devine as well as Dr. F. Walley, the external examiner from the Department of Soil Science. The technical assistance of Mr. Gerry Stuber is gratefully acknowledged.

Financial support from the Natural Sciences and Engineering Research Council (NSERC) of Canada, Dow AgroSciences Canada Inc. and the Saskatchewan Pulse Crop Development Board (SPCDB) is also gratefully acknowledged.

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1.0 INTRODUCTION

Agriculture in Saskatchewan has changed much over the past two decades. Reduced tillage and diversification into special crops, especially pulse crops, are among the most notable changes. These changes have resulted in the need for increased research into conservation tillage systems for pulse crop production and protection in Saskatchewan.

Pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) are the dominant pulse crops grown in Saskatchewan and the rest of the prairie provinces. Producers who have adopted a conservation tillage system direct seed many of their pea and lentil crops. These crops are not good competitors with weeds and effective weed control is necessary to maximize seed yield.

In Saskatchewan, tillage is used mainly for weed control. However, herbicides can be economically substituted for mechanical tillage (Lafond *et al.*, 1993, Arshad *et al.*, 1994). Few herbicides are registered for weed control in pea and even fewer in lentil (Saskatchewan Agriculture and Food, 1997a). The broad-spectrum, soil-incorporated dinitroanilines, which include ethalfluralin and trifluralin, are an important group of herbicides commonly used in pea and lentil for the control of grassy weeds and broadleaves, but not including those weeds in the *Brassicaceae* family. Other than the dinitroanilines, most of the registered herbicides are post-emergent products for control of grassy weeds.

In a direct seeding system, the use of soil-incorporated herbicides, such as the dinitroanilines, was previously thought not feasible. Currently, no suitable alternatives to the dinitroaniline herbicides are available for control of kochia (*Kochia scoparia* (L.) Schrad.), wild buckwheat (*Polygonum convolvulus* L.), redroot and prostrate pigweed (*Amaranthus retroflexus* L. and *Amaranthus graecizans* L.) and other hard-to-control weeds in direct-seeded pea and lentil.

In a zero-tillage system, herbicides replace tillage for weed control, both in the fallow year and in the spring prior to seeding. When tillage is not part of the weed management system, weed seeds are not incorporated into the soil. Rather, they become concentrated at the soil surface. With most weed seeds at the soil surface, it is reasonable to assume that soil-incorporated herbicides could be applied to the soil surface, come in contact with the germinating weed seeds and control them. If the chemical and physical properties of the herbicide are such that it will not dissipate into the environment if left unincorporated, it may be suitable for use in a direct seeding system.

The trend towards reduced tillage is being driven by a desire to reduce production costs and address soil conservation issues while maintaining or increasing crop yields. Reducing tillage saves time, labour, fuel and machinery inputs (Unger, 1990, Weston, 1990). In many cases, these savings will be partially offset by increased herbicide costs, so the economics of reduced tillage must be reasonable if producers are to achieve a profit. Lafond *et al.* (1993) reported that net returns for field pea produced in either a zero or minimum tillage system were significantly greater than those produced in a conventional tillage system.

Pea and lentil are capable of deriving much of their nitrogen requirement from the atmosphere. A legume plant with a healthy root system, effectively inoculated with *Rhizobium* bacteria, should be an efficient N_2-fixer. Any crop production or protection system that interferes with the developing pea or lentil plant has the potential to reduce the N_2-fixing ability of the plant. Thus an examination of the effect of herbicides used in direct-seeding systems on N_2-fixation by these crops is warranted.

An agronomically-sound method of broad-spectrum weed control for direct-seeded pea and lentil is necessary before pulse crop producers will include pea and lentil in their crop rotations if they use a direct seeding system. The objective of this research was to develop a cost-effective, efficacious weed control strategy for pea and lentil in direct-seeding systems and to evaluate its effect on N_2-fixation by these crops.

2.0 LITERATURE REVIEW

2.1 Pea and Lentil Production

Crop production in Western Canada is diversifying to include pea and lentil. These two pulse crops are increasing in popularity because of their economic value and their ability to provide nitrogen to subsequent crops through nitrogen mineralization (Bremer and van Kessel, 1990). In Saskatchewan in 1997, lentil was sown on approximately 315, 000 hectares, while approximately 607, 000 hectares were sown to pea (Saskatchewan Agriculture and Food, 1997b).

Pea and lentil can be sown early in the season, as soon as the top 3 cm of soil reaches 5°C (Slinkard and Holm, 1989, Slinkard *et al.*, 1995). Pea and lentil have hypogeal emergence in which the cotyledons remain below ground. This characteristic gives them the ability to withstand considerable spring frost. Since lentil has a strongly indeterminate growth habit, some type of environmental stress is needed to initiate pod formation. Early-seeded lentil has a prolonged vegetative and reproductive period and usually yields higher than late-seeded lentil (Slinkard and Holm, 1989). Wall (1994) claimed that the yield potential of late seeded lentil was limited by a shortened vegetative and reproductive period.

Early seeding of pea and lentil is important to maximize seed yield (Slinkard and Holm, 1989). In Saskatchewan, pea is grown in most soil zones, but is best suited to the Black soil zone (Slinkard *et al.*, 1995). Lentil is moderately drought resistant and is best suited to the Brown and Dark Brown soil zones (Slinkard and Holm, 1989).

Pea and lentil form a symbiotic relationship with the *Rhizobium leguminosarum* bv. *vicea* population that exists in the soil or is applied to the seed as an inoculant and, thus, are capable of deriving nitrogen from the atmosphere (Slinkard *et al.*, 1995). Pea and lentil also use available soil nitrogen. Nitrogen fertilizer is often applied with the seed at the time of seeding at a rate not exceeding 20 kg ha^{-1}. Rates higher than this may be toxic to the seedling and will likely cause the plant to use this nitrogen fertilizer rather than fix N_2 from the atmosphere (Reichardt *et al.*, 1987). Applied nitrogen fertilizer is used for crop establishment until the *Rhizobium* infection of the root hairs occurs and the plant can obtain its nitrogen requirement from the atmosphere. Phosphate should be applied with the seed at rates not exceeding 22 kg ha^{-1} in lentil and 16 kg ha^{-1} in pea (Saskatchewan Agriculture and Food, 1995c). It is important to have adequate phosphorus fertilization to ensure efficient N_2-fixation.

Pea and lentil are poor competitors with weeds. Wild mustard (*Brassica kaber* [D.C.] Wheeler var. *pinnatifida* [Stokes] Wheeler) competes strongly for moisture and light in field pea and has reduced pea seed yield by up to 35% (Wall *et al.*, 1991). Grassy and broadleaf weeds can cause a loss of up to 75% of the potential lentil yield (Slinkard and Holm, 1989).

A closed canopy, helps reduce weed competition, but is slow to develop in both crops. Weeds, such as buckwheat and kochia, can interfere with the harvesting process and can contribute to downgrading of the harvested product if weed seeds are present in the grain sample. Highly efficient weed control early in the growing season is required for maximum crop seed yield. Season-long weed control will reduce the incidence of weeds in the harvested sample, as well as costs associated with cleaning and transportation of dockage (Slinkard *et al.*, 1995).

2.2 Direct Seeding

Zero tillage and minimum tillage are conservation tillage systems in which a minimum of 30% of the soil surface is covered by crop residue (Swanton *et al.*, 1993, Derksen *et al.*, 1995). Direct seeding is the placement of seed directly into the undisturbed stubble of the previous crop, and no tillage operations occur after harvest or prior to seeding. Direct seeding is a part of all zero-till and many minimum tillage systems. Direct seeding can be either a low or high soil disturbance operation, depending on the type of opener used to place the seed and fertilizer.

In a direct-seeding system, the residue from the previous crop is left on the soil surface. Many benefits are derived from maintaining this residue, including protection of soil from wind and water erosion, protection of emerging crop seedlings, snow trapping, and increased water infiltration into the soil (Weber and Lowder, 1985, Unger, 1990, Fawcett *et al.* 1994). The elimination of tillage also saves time, labour, fuel and machinery costs.

Many authors have reported that over a number of years, the weed population in a reduced-tillage system will change in composition from that which was present in the conventional tillage system (Arshad *et al.*, 1995, Blackshaw *et al.*, 1994). Others (Derksen *et al.*, 1993) reported that weed species changes in a two-year study were more influenced by location and year rather than tillage system. Swanton *et al.* (1993) claimed that many changes in weed species composition would take place in a reduced-tillage system, including volunteer crops as weeds and an increase in wind-disseminated species, biennials, and perennials. Derksen and Thomas (1996) found that dandelion (*Taraxacum officinale* L.) was strongly associated with reduced tillage systems. The effect of a changing management regime, such as adoption of a reduced or zero tillage system, may take 4 to 10 years to reach equilibrium levels with respect to weed populations, crop yield and soil characteristics (Dick and Daniel, 1987, Gebhardt *et al.*, 1985 as cited by Swanton *et al.*, 1993).

Direct seeding eliminates tillage as a method of weed control and increases the reliance on herbicidal and cultural weed control strategies. Because the herbicide options for pea and lentil are fewer than for cereals, including these pulse crops in the rotation requires careful herbicide selection and application. Pea and lentil are also susceptible to residues of many herbicides used in cereal crops (Friesen and Wall, 1986).

2.3 Dinitroaniline and Other Herbicides for Pea and Lentil

A limited number of herbicides are registered for use in pea and lentil (Table 2.1). Many herbicides registered for use in these crops are used to control grassy weeds. Fewer herbicides are registered for control of broadleaf weeds. While considerably more post-emergent herbicides are registered for broadleaf weeds in pea than in lentil, the selection of pre-emergent herbicides remains limited (Malik and Townley-Smith, 1990). Pre-emergent herbicides, such as ethalfluralin and trifluralin, are commonly used to control both grassy and broadleaf weeds in pea and lentil in conventional tillage systems, but are not yet registered for use in a direct-seeding system.

Metribuzin is currently the only post-emergent herbicide registered for broadleaf-weed control for both pea and lentil. Most often, metribuzin is applied in sequence with trifluralin or ethalfluralin, but may be incorporated into the soil with the dinitroaniline herbicides under some soil conditions. Metribuzin controls many broadleaves in the *Brassicaceae* family, but its performance in the typical heavy trash cover in a direct-seeding system often is reduced (Banks and Robinson, 1982). Moreover, Malik and Townley-Smith (1990) found that stinkweed (*Thlaspi arvense* L.) control with metribuzin was better when it was applied as a post-emergent treatment as opposed to a pre-emergent treatment. The efficacy of metribuzin, applied pre-emergence without incorporation, should be assessed.

An effective broad-spectrum, pre-emergent herbicide suitable for application in a direct-seeding system would benefit pulse crop producers on the prairies. A combination of the dinitroanilines, metribuzin applied pre- or post-emergence, and glyphosate may be suited for a weed control program in direct seeded pea and lentil and should be evaluated.

Table 2.1 Herbicides registered for use in pea and lentil in a conventional tillage system in Saskatchewan (adapted from Saskatchewan Agriculture and Food, 1997a).

Herbicide	**Crop**[z]	**Pre or PoE**[y]	**Weed spectrum**
Ethalfluralin	P, L	Pre	grasses and broadleaves
Trifluralin	P, L	Pre	grasses and broadleaves
Triallate	P	Pre	grasses
Metribuzin	P, L	Pre and PoE	broadleaves
Sethoxydim	P, L	PoE	grasses
Diclofop methyl	P, L	PoE	grasses
Quizalofop ethyl	P, L	PoE	grasses
MCPA-Na salt	P	PoE	broadleaves
Bentazon	P	PoE	broadleaves
Imazethapyr	P	PoE	grasses and broadleaves
Imazethapyr/imazamox (1:1)	P	PoE	grasses and broadleaves
MCPB/MCPA (15:1)	P	PoE	broadleaves
TCA	P	PoE	grasses
Fenoxaprop-p-ethyl + fluazifop-p-butyl	P, L	PoE	grasses
Fluazifop-butyl	P, L	PoE	grasses

[z] P = pea, L = lentil.
[y] Pre = preemergence, PoE = postemergence.

Trifluralin and ethalfluralin are dinitroaniline herbicides that inhibit plant growth by preventing microtubule formation in the developing nucleus (Vaughn and Lehnen, 1991, Devine *et al.*, 1993). The dinitroanilines must be in contact with the germinating weed seed or root to inhibit weed growth (Devine personal communication, 1998). The current label recommends that trifluralin and ethalfluralin be incorporated twice, at right angles, at least 3 days apart, to a depth of 10 cm (DowElanco Canada Inc., 1996). This incorporation requirement precludes the use of trifluralin and ethalfluralin in a direct-seeding system where the herbicide would be applied to the soil surface and left unincorporated. If the weed seeds are dispersed through the top 7.5-10 cm of soil, then the herbicide must also be distributed in this area to be effective. In many zero and reduced-tillage systems, herbicides with low leaching potentials remain at or near the soil surface (Thomas, 1985). In a direct-seeding system, the weed seeds accumulate on the surface and the potential exists for the use of surface-applied dinitroaniline herbicides for weed control.

The dinitroaniline herbicides, however, can be easily dissipated by volatilization, photodecomposition and microbial degradation (Grover *et al.*, 1988, Weber 1990, Endres and Ahrens, 1995). The potential for volatilization varies between the dinitroaniline herbicides and some, such as ethalfluralin, are more suited to surface application than others (Weber, 1990). Herbicide dissipation is greatly reduced if the herbicide is incorporated into the soil. Loss of trifluralin and ethalfluralin is reduced by applying the herbicide just prior to soil freeze-up and winter snowfall. Grover *et al.* (1988) confirmed that no significant losses of incorporated triallate or trifluralin occurred between 26 October and 9 April in experiments conducted at Regina, SK.

Without the use of the dinitroanilines in a direct-seeding system, weed control becomes more difficult. Broadleaf weeds such as redroot pigweed, wild buckwheat, purslane (*Portulaca oleracea* L.), prostrate knotweed (*Polygonum aviculare* L.), cow cockle

(*Vaccaria pyramidata* L.), prostrate pigweed, corn-spurry (*Spergula arvensis* L.) and kochia are controlled by soil-incorporated trifluralin and ethalfluralin, but cannot be controlled by other registered herbicides. Ethalfluralin, a broader spectrum herbicide than trifluralin, will also suppress hemp-nettle (*Galeopsis tetrahit* L.), lady's thumb (*Polygonum* spp.), Russian thistle (*Salsola pestifer* A. Nels.), cleavers (*Galium aparine* L.), and nightshade (*Solanum* spp.). Along with these broadleaves, the dinitroanilines also control the major annual grass weeds in pea and lentil. The use of dinitroanilines, in combination with metribuzin, in a direct-seeding system, could eliminate the need for post-emergent herbicides.

Research has been conducted on the surface application of the granular dinitroaniline herbicides in North Dakota. Ahrens and Endres (1996) reported that unincorporated trifluralin and ethalfluralin applied in mid-October at 1.12 kg ha^{-1} resulted in 88-92% control of green foxtail (*Setaria viridis* [L.] Beauv.), as determined by visual ratings the following June. In another study, Endres and Ahrens (1995) found that trifluralin applied in the fall at 0.56 kg ha^{-1} and left unincorporated provided 76% control of green foxtail. In the same study, trifluralin incorporated with a rotary hoe controlled 81-88% of the green foxtail. The slight incorporation from the rotary hoe may have been adequate to reduce herbicide losses enough to increase trifluralin efficacy.

To compensate for losses, higher rates of trifluralin and ethalfluralin may be required if the herbicides are not incorporated. Endres and Ahrens (1995) reported that a large amount of soil-surface residue minimized herbicide losses by photodecomposition and volatilization. Moreover, a concentrated layer of herbicide at the soil surface may provide more weed control than the diluted layer following incorporation and, thus, the lower rate may be sufficient for weed control.

The use of ethalfluralin in a direct-seeding system will allow for potential pre-emergent control of troublesome weeds, such as kochia, chickweed (*Stellaria media* [L.] Vill.), and wild buckwheat, as well as the suppression of other broadleaves not controlled by the currently-registered herbicides. Wild oat (*Avena fatua* L.), green foxtail and volunteer wheat (*Triticum aestivum* L.) also have the potential to be controlled by ethalfluralin in a direct-seeding system. A pre-emergent application of triallate/trifluralin (10:4) in direct-seeded pea and lentil could control wild oat, green foxtail and yellow foxtail (*Setaria glauca* (L.) Beauv.) prior to crop emergence. Surface application of triallate, a volatile herbicide, is currently registered for use in western Canada.

Metribuzin applied in the fall or a pre-seeding application of glyphosate and post-emergent MCPA-Na salt in pea and metribuzin in lentil were evaluated to supplement the dinitroaniline herbicides weed spectrum because of their suitability for use on the crop and their relatively low cost.

2.4 N_2-fixation

Crops in the *Leguminosae* family growing in association with *Rhizobium* spp., are capable of deriving some N through symbiotic N_2-fixation. *Rhizobium leguminosarum* bv. *vicea* is capable of initiating nodules and establishing an effective N_2-fixing association with pea and lentil. These bacteria colonize the root hairs of the developing seedling. The process by which the bacteria infect the root and convert atmospheric N_2 to NH_3^- has been well documented (Bergensen, 1978). Herbicides may directly affect legume-*Rhizobium* symbiosis through inhibition of nodulation and nitrogenase activity, or indirectly, through effects on root growth and plant development (Germida *et al.*, 1988). Inhibition of lateral root growth is a symptom typical of dinitroaniline herbicide injury.

The effects of agrochemicals on N_2-fixation in legume species have been studied previously (Cardina *et al.*, 1986, Kumar and Kolar, 1989, Clark and Mahanty, 1991). Kumar and Kolar (1989) found that 1.5 kg ai ha^{-1} of pendimethalin (a dinitroaniline herbicide) did not affect nodule number per plant on lentil inoculated with *Rhizobium*. Cardina *et al.* (1986) studied the effects of atrazine on nodulation of crown vetch (*Coronilla varia* L.) and found that herbicidal effects on nodulation were likely due to plant phytotoxicity rather than any direct effect on rhizobial growth or nitrogenase activity. Clark and Mahanty (1991) studied the effects of five herbicides on growth and N_2-fixation in white clover *(Trifolium repens* L.) and concluded that MCPB, paraquat, bentazon, fluazifop and pronamide all had the potential to be harmful to the growth and

N_2-fixation of white clover under specific soil and moisture conditions. Factors such as soil pH, moisture and microbial composition affected herbicide toxicity.

Germida *et al.* (1988) reported that metribuzin and trifluralin, applied at field rates, reduced N_2-fixation potential (as determined by acetylene reduction assay) in lentil. Also, if pea and lentil were unduly stressed by unfavourable growing conditions, nodulation and N_2-fixation may be adversely affected by herbicides. Sprout et al. (1988) reported that metribuzin reduced both root fresh weight and shoot dry weight in lentil when inoculated with most strains of *Rhizobium* tested. On a per plant basis, acetylene reduction activity was lower in those plants treated with metribuzin. The effects of metribuzin on lentil and pea in a field environment require further investigation.

The effects of glyphosate on nodulation have been studied in the laboratory. Mårtensson (1992) found that glyphosate applied at 60 mg l^{-1} to the root of red clover (*Trifolium pratense* L.) either four days before, at the same time as, or four days after *Rhizobium* inoculation reduced the number of nodules formed. Eberbach and Douglas (1989) also reported that glyphosate inhibited the nodulation ability of *Rhizobium trifolii*, on *Trifolium subterraneum* L.. The effects of a glyphosate burn-off treatment on nodulation and N_2-fixation by *Rhizobium leguminosarum* bv. *vicea* in pea and lentil have not been studied under field conditions.

With an increase in the use of herbicides in direct-seeding systems, it is important to determine the effects of such treatments on the *Rhizobium*-legume symbiotic relationship (Lal and Lal, 1988). Herbicides that affect the health of the root system or above-ground biomass of the plant have the potential to interfere with N_2-fixation. MCPA-Na salt is more toxic to the root than the shoot of the plant (A. E. Slinkard, personal communication). The effect of herbicides on N_2-fixation by *Rhizobium* in different tillage systems requires further investigation.

The natural abundance ^{15}N and ^{15}N-isotope dilution methods of quantifying atmospheric N_2-fixation have been used extensively in studies with pea and lentil (Rennie, 1984, Rennie and Dubetz, 1986, Smith *et al.*, 1987, Bremer and van Kessel, 1990). Many of the studies were conducted to compare the effectiveness of the natural abundance ^{15}N method with the ^{15}N-isotope dilution technique. The two methods, when assessed over a three-year period, provided similar estimates of N_2-fixation in lentil (Bremer and van Kessel, 1990).

The need for a new application method for ethalfluralin and triallate/trifluralin (10:4) and the lack of research on the effects of glyphosate applied as a pre-seeding burn-off, and metribuzin soil- and foliar-applied, supports an investigation into their effects on nitrogen fixation in pea and lentil, as determined by the ^{15}N natural abundance and ^{15}N isotope dilution techniques.

3.0 MATERIALS AND METHODS

3.1 Experimental Design and Statistical Analysis

Field experiments were conducted in 1995 and 1996 at the University of Saskatchewan Kernen and Goodale Research Farms. Treatments were grouped in a randomized complete block design with four replications (Table 3.1). Randomization varied for each site and year.

Three rates of ethalfluralin (0.84, 1.1 and 1.4 kg ai ha^{-1}) and one rate of triallate/trifluralin (10:4) (1.96 kg ai ha^{-1}) were the main herbicide treatments used in the experiments. These rates were chosen because ethalfluralin and triallate/trifluralin (10:4) are registered for use at 1.1 kg ai ha^{-1} and 1.96 kg ai ha^{-1}, respectively. Three types of application were used for the fall herbicide treatments: a surface application (no incorporation), a shallow incorporation (4 cm) or a conventional incorporation (recommended to a 10 cm depth). Fall-applied metribuzin or a spring-pre-seeding glyphosate burn-off followed by post-emergent herbicides for broadleaf weed control were applied in combination with the fall applied dinitroaniline herbicides. (For complete treatment lists refer to Appendix Tables A1.1-A1.6).

Table 3.1 Generalized plot plan used for all experiments with treatment number for each plot, half of each plot seeded to pea, the other half to lentil at Kernen and Goodale, 1995 and 1996.

P[z] L	1	P L	10	P L	11	P L	14
P L	2	P L	15	P L	4	P L	18
P L	3	P L	9	P L	6	P L	11
P L	4	P L	12	P L	1	P L	19
P L	5	P L	6	P L	17	P L	3
P L	6	P L	16	P L	15	P L	7
P L	7	P L	17	P L	8	P L	6
P L	8	P L	19	P L	13	P L	4
P L	9	P L	11	P L	5	P L	16
P L	10	P L	4	P L	14	P L	5
P L	11	P L	18	P L	2	P L	9
P L	12	P L	7	P L	19	P L	1
P L	13	P L	5	P L	10	P L	2
P L	14	P L	13	P L	12	P L	15
P L	15	P L	3	P L	9	P L	8
P L	16	P L	2	P L	16	P L	13
P L	17	P L	14	P L	18	P L	10
P L	18	P L	8	P L	3	P L	12
P L	19	P L	1	P L	7	P L	17

[z] P = pea, L = lentil.

The experiments varied with respect to post-emergent herbicide treatments; post-emergence herbicide applications depended on weed population present at each location each year. Pre-emergent treatments differed only in the rate of fall-applied metribuzin.

Plots were 2.2-2.5 m wide and 6.5 -12 m long. Plot size varied between locations and years, depending on the amount of available land.

At both sites in 1995 and 1996, crop tolerance and weed control were determined by making the following observations and measurements:

1) crop emergence (plants m^{-2} at 11-13, 17-18, and 23-26 days after seeding (DAS))
2) crop tolerance (visual assessment)
3) weed control (visual assessment)
4) weed biomass
5) N_2-fixation, and
6) crop seed yield

Data were subjected to the analysis of variance to determine significant treatment effects (Statistical Analysis Systems Institute, 1987). Significant treatment effects were further analyzed using a non-orthogonal set of contrasts to determine individual herbicide and tillage effects. Bartlett's test for homogeneity of variances was used to determine if data on weed biomass or crop tolerance could be combined, but in most instances heterogeneity of variances existed. Data were combined for analysis when appropriate. Where weed control systems data were highly variable from one experiment to the next, data are presented individually for year and location.

While different treatments between locations and years often limit the use of a combined analysis, the dynamics of weed populations call for variable weed control systems. When the weed control systems are averaged across experiments, the effect of the systems on weed control and crop tolerance can be assessed across locations for the time period in question.

Fall and early spring treatments were identical across years and locations. Thus, a combined analysis for crop emergence over years and locations was possible. Treatment means were rounded to the precision indicated by one-quarter of their standard error (Baker, 1995).

3.2 Site Description

The Kernen location is characterized by a Sutherland clay loam soil having a composition of 23% sand, 41% silt and 36% clay. The Goodale location is a lighter soil classified as a Bradwell fine sandy loam with a composition of 51% sand, 29% silt and 20% clay. The soil at Kernen has an organic matter content of 4.5% and a pH of 7.0 in the 0-8 cm depth. The soil at Goodale has an organic matter content of 3.5% and a pH of 6.8 in the 0-8 cm depth. The varying soil types at the two locations could result in different herbicide efficacy due to both differential herbicide binding and growing conditions.

Soil tests were conducted each fall to determine available N, P, K, and S in the 0-8, 8-15, 15-30 and 30-60 cm depths (Table 3.2). Soil samples were analyzed by Plains Innovative Laboratory Services, Saskatoon, SK in 1994 and Enviro-Test Laboratories, Saskatoon, SK in 1995.

Table 3.2 Soil fertility levels in the fall at Kernen and Goodale, 1994 and 1995.

		Nitrate		**Phosphate**		**Potassium**		**Sulphate**	
Location	**Depth**	**1994**	**1995**	**1994**	**1995**	**1994**	**1995**	**1994**	**1995**
	(cm)	Available Concentration ($\mu g\ g^{-1}$)							
Kernen	0-8	26.8	13.4	35.5	41.0	742	580	11.0	8.6
	8-15	18.0	9.0	7.3	4.9	503	327	8.6	7.2
	15-30	13.6	7.0	2.5	1.4	279	276	7.2	6.4
	30-60	11.6	6.4	1.2	0.7	216	238	8.8	6.8
Goodale	0-8	12.2	5.2	28.6	31.6	489	480	10.0	4.6
	8-15	6.0	9.6	7.8	11.8	241	229	10.8	5.2
	15-30	4.0	5.8	3.0	4.9	129	155	84.0	5.6
	30-60	2.8	5.4	2.8	3.5	102	137	2060.0	9.0

In 1994, the year prior to the first year of field research, the experimental areas were chem-fallowed wheat stubble. Glyphosate (356 g L^{-1} SN) was applied 2-3 times in the fallow year at the recommended rate. In each of the two years previous to the chem-fallow, the areas were in a minimum tillage system and seeded to hard red spring wheat.

3.3 Fall Herbicide Application

Prior to fall herbicide application, weed seeds were spread on the soil surface to supplement the existing weed population and mimic the conditions of zero-till. Wheat, wild oat and green foxtail seeds were applied at both locations in both years. Wheat seed was applied at 10 kg ha^{-1} in 1995 and at 20 kg ha^{-1} in 1996. In both years, wild oat seed was applied at 24 kg ha^{-1} and green foxtail seed was spread at 250 seeds m^{-2}. In 1996, canola was seeded at both locations to mimic the *Brassicaceae* weed species. Kochia seed was applied in the fall and wild buckwheat seed early in the spring at Kernen only. Kochia and buckwheat seeds were applied at only one location due to seed supply limitations. Both kochia and wild buckwheat seeds were applied at approximately 200 seeds m^{-2} with a hand-held grass seed spreader. The spring-seeded wild buckwheat was applied after incorporation of specific herbicide treatments thereby reducing incorporation of the seed.

Fall-herbicide application and incorporation occurred between the 23-26th of October (Table 3.3). Fall application of soil-applied herbicides is best done immediately prior to snowfall and soil freeze-up. With the exception of metribuzin, the same herbicide treatments were applied in the fall of 1994 and 1995 at both locations. Metribuzin (75% DF) was applied at the recommended rate for the soil organic matter content. In both years, 0.28 kg ai ha^{-1} were applied at Goodale and 0.36 kg ai ha^{-1} were applied at Kernen. Metribuzin was applied with either a hand-held wand sprayer or a 3-point hitch tractor-mounted plot sprayer, both calibrated to deliver 100 L ha^{-1}. Ethalfluralin (5% G) and triallate/trifluralin (10:4) (14% G) were applied with a Valmar Airflow 120 granular herbicide applicator (Valmar Industries, Elie MB).

Table 3.3 Time of fall herbicide application and incorporation at Kernen and Goodale, 1994 and 1995.

Year	Location	Herbicide	Application date	Incorporation date
1994	Kernen	Metribuzin	23 Oct.	24 Oct.
		Ethalfluralin	24 Oct.	
	Goodale	Metribuzin	23 Oct.	24 Oct.
		Ethalfluralin	24 Oct.	
1995	Kernen	Metribuzin	23 Oct.	23 Oct.
		Ethalfluralin	23 Oct.	
	Goodale	Metribuzin	24 Oct.	25-26 Oct.
		Ethalfluralin	25 Oct.	

After herbicide application in the fall of 1994, conventional incorporation treatments were worked once with a tandem disc to a depth of 10 cm followed by a tine harrow operation. These plots were worked again in the spring to ensure adequate distribution of the herbicide. The weedy check was also worked at this time to provide mechanical weed control. In the fall of 1995, due to hard soil conditions, the disc operation had to be supplemented with a spring cultivation with a medium-duty cultivator to provide acceptable incorporation of the herbicide in the conventional tillage treatments. The cultivator was also used for weed control in the weedy check in the spring of 1996.

Shallow incorporation treatments were tilled twice in the fall with a rotary harrow to a depth of approximately 4 cm. This shallow incorporation was used to ensure the herbicide had adequate contact with the soil surface and enhanced protection from volatilization and photodecomposition losses. Surface-applied treatments were not incorporated in either spring or fall.

3.4 Spring Herbicide Application

All herbicides were applied at an operating pressure of 276-290 kPa with Teejet 80015 nozzles. Glyphosate was applied as a pre-seeding burn-off to those treatments that did not receive a fall application of metribuzin, but not to the conventional tillage treatments and the weedy check. Although the weed population was not sufficient at Kernen in 1995 to economically justify glyphosate application, it was applied to determine the effects of a glyphosate burn-off treatment on nitrogen fixation. Glyphosate was applied at 0.27 kg ai ha^{-1} in 100 L ha^{-1} with either a hand-held wand sprayer or a 3-point hitch tractor-mounted plot sprayer. The weed species present at the time of glyphosate application included stinkweed, volunteer wheat and flixweed (*Descurania sophia* [L.] Webb). Timing of spring glyphosate burn-off applications in 1995 and 1996 is given in Table 3.4. The glyphosate burn-off was followed by post-emergent herbicides for broadleaf weeds as needed, taking into consideration the economics of herbicide selection and the need to spray.

Table 3.4 Spring glyphosate application date and weather conditions at Kernen and Goodale, 1995 and 1996.

Year	**Location**	**Application date**	**Time of day**	**Temperature (°C) / R.H. (%)**
1995	Kernen	10 May	1500	27 / 22
	Goodale	9 May	1100	20 / 43
1996	Kernen	23 May	1000	11 / 66
	Goodale	22 May	1000	7 / 74

3.5 Seeding

Seeding date was later than desired in both years due to cool, wet spring weather (Table 3.5). As a major weed control treatment in the experiments was spring glyphosate burn-off, seeding was also delayed until some weeds emerged and could be controlled with glyphosate.

Table 3.5 Date of seeding pea and lentil at Kernen and Goodale, 1995 and 1996.

Year	Location	Crop	Date
1995	Kernen	Lentil	12 May
		Pea	12 May
1996		Lentil	27 May
		Pea	26 May
1995	Goodale	Lentil	11 May
		Pea	11 May
1996		Lentil	24 May
		Pea	24 May

Crops were sown according to standard practices used in Saskatchewan. A Rogers No-Till Conservation Plot Drill (Rogers Innovative Inc., Saskatoon SK) with V-disc openers and 17.5 cm spacings was the seeding implement used in both years. Lentil cv. Laird was seeded at 110 kg ha^{-1} and pea cv. Grande at 202 kg ha^{-1} in both years at both locations. Both crops were fertilized at a rate of 18 kg P_2O_5 ha^{-1} seed placed using triple superphosphate (0-45-0) as the phosphorus source. No nitrogen was applied with the crop to facilitate the nitrogen fixation component of the research. Moreover, soil tests indicated sufficient soil nitrogen in most experiments (Table 3.2). *Rhizobium* inoculant was applied at twice the recommended rate in all experiments so that if the experimental area had never been cropped to pea or lentil, the higher rate would ensure establishment of a soil *Rhizobium* population. The inoculants used were N-Prove® (Philom Bios Inc., Saskatoon SK) in 1995 and Nitragin® (Nitragin Co., Milwaukee WI) in 1996.

3.6 Post-Emergent Herbicide Application

Herbicides for broadleaf weed control, namely metribuzin for lentil and MCPA-Na (300 g L^{-1} SN) salt for pea, were applied post-emergence to the crop to control weeds not covered in the dinitroaniline herbicide weed spectrum or not yet emerged at the time of glyphosate application. Post-emergent herbicides were also applied to the conventional tillage treatments, when sufficient weed populations were present.

Herbicides for broadleaf weeds were applied when the crop and weeds were at the recommended stages for maximum weed control and crop tolerance as recommended by Saskatchewan Agriculture and Food (1997a). The weed population included a number of broadleaf weeds and varied slightly between locations and years. Major broadleaf weed concerns included: wild buckwheat, stinkweed, flixweed, lamb's-quarters (*Chenopodium album* L.), kochia, volunteer canola (*Brassica napus*), narrow-leaved hawk's-beard (*Crepis tectorum* L.), and redroot pigweed. Other broadleaf weeds such as prickly lettuce (*Lactuca serriola* L.) and round-leaved mallow (*Malva rotundifolia* L.) were present, but not in high enough densities to be a concern.

The broadleaf weed population at Kernen in 1995 was not sufficient to warrant post-emergent herbicide application. Metribuzin was applied to lentil at 0.16 kg ai ha^{-1} in both years at Goodale and in 1996 at Kernen. MCPA-Na salt was applied to pea at 0.46 kg ai ha^{-1} in 1996 at both locations and 0.8 kg ai ha^{-1} in 1995 at Goodale. MCPA-Na salt was applied at 200 L ha^{-1} water in both years. Metribuzin was applied in 100 L of water ha^{-1} in 1995 and 150 L ha^{-1} in 1996. Shallow seeding in 1996 allowed for potential root uptake of foliar-applied metribuzin and possible crop injury. Devine (personal communication, 1996) recommended that a higher water volume would lessen the impact of metribuzin injury to the crop. Metribuzin was applied with a hand-held sprayer in 1995 and a 3-point hitch tractor-mounted plot sprayer in 1996. Timing of metribuzin and MCPA-Na salt application varied between locations and years, as did the weather conditions at the time of herbicide application (Tables 3.6 and 3.7).

3.6 Weather conditions, crop stage and time of metribuzin application to lentil at Kernen and Goodale, 1995 and 1996.

Location	Year	Application date	Time of day	Temperature (°C) / R.H. (%)	Crop stage (BBCH)
Kernen	1995[z]	13 June	1000	25 / 33	16-17
	1996	24 June	1010	13 / 98	18
Goodale	1995	1 June	1500	24 / 43	12-14
	1996	12 June	2000	22 / 27	15

[z] Treatment 2 only.

3.7 Weather conditions, crop stage and time of MCPA-Na salt application to pea at Kernen and Goodale, 1995 and 1996.

Location	Year	Application date	Time of day	Temperature (°C) / R.H. (%)	Crop stage (BBCH)
Kernen	1995[z]	14 June	0830	21 / 46	16
	1996	24 June	0730	14 / 98	16
Goodale	1995	5 June	1100	24 / 70	16
	1996	21 June	0730	8 / 89	16

[z] Treatment 2 only.

3.7 Weed Control

Weed control was assessed using the 0-100% visual rating system approved by the Canadian Expert Committee on Weeds (ECW) with 0 being no control and 100% indicating complete control of weeds. The minimum acceptable level of weed control is 80%. Visual control ratings for grass weeds were based on the treated plot as a whole and were not determined individually for both crops. Weed control was assessed at two standard time periods, 40-43 DAS and 53-57 DAS. Some weeds were not present at the first rating date and, thus, ratings are presented only for the second rating date.

Weed control was also assessed by counting weeds in two 0.5 m^2 quadrats per plot. Weeds were then bagged and dried for 48 hrs at 80°C and dry weights ($g\ m^{-2}$) were determined. Individual counts and weights were determined for green foxtail, wild oat and volunteer wheat at both locations in both years. Total broadleaf weed count, identification and dry weight ($g\ m^{-2}$) were also determined for each of the eight experiments. Weed biomass determinations were made between 60 and 76 DAS, when significant visual differences in weed control among the treatments were evident.

3.8 Crop Tolerance

A number of parameters were used to assess crop tolerance. Starting at 11-13 DAS, crop emergence was determined at weekly intervals for three weeks. Emerged plants were marked and counted in four random 0.25 m^2 quadrats per plot. The same quadrats were used for all three weekly counts, counting only unmarked plants on each successive date.

Crop injury (stunting and/or chlorosis) was assessed at 40-43 and 53-56 DAS. Visual estimates of crop injury were also made on a 0-100% scale with 0 indicating no crop injury and 100 indicating complete crop death. Crop injury of 10% or less is considered acceptable by the ECW.

The crops were desiccated with diquat (200 g L^{-1} SN) at 0.4 kg ai ha^{-1} in 200 L of water. Pea did not require desiccation as it matured naturally, but was desiccated at the recommended stage for lentil desiccation due to the layout of the experiments.

Crop seed yield was determined at the end of the season by harvesting each plot with a Hege small plot combine (Hege Equipment, Norwich KS) with a 1.2 m wide cutter bar.

Seed sample size ranged from approximately one to four kg. As plot size varied among locations, all seed yield data were transformed to kg ha^{-1}. Seed samples were dried in a drying room set at 30°C for 3-4 days to bring the samples to a uniform moisture content. Seed from each harvested plot was cleaned with a Carter Dockage Tester (Carter Day Industries, Minneapolis MN) to remove foreign material, including weed seeds, and cracked and split pea or lentil seeds.

3.9 N_2-fixation

The objectives of this experiment were to determine if herbicide treatments had any effect on atmospheric N_2-fixation. N_2-fixation was determined using both the ^{15}N isotope dilution method and the natural ^{15}N abundance method as described by Peoples *et al.* (1989). Because of financial restrictions, only six treatments were analyzed with both methods, the remaining 13 were analyzed using the natural ^{15}N abundance method only. Both methods have advantages and disadvantages. The natural ^{15}N abundance ($\delta^{15}N$) method is limited by the spatial and temporal variability in $\delta^{15}N$ (Bremer and van Kessel, 1990). The enrichment method is limited by the choice of a non-N_2-fixing reference plant (Peoples *et al.*, 1989). Differences in the rooting patterns of the reference and N_2-fixing plants contribute to high coefficients of variation (Reichardt *et al.*, 1987). Some data sets contained negative N_2-fixation values or values in excess of 100% nitrogen derived from atmosphere (Ndfa), but these results are not presented.

3.9.1 ^{15}N Isotope Dilution Method

This method was used to assess N_2-fixation in 6 of the 19 treatments. Six treatments were analyzed, three of which included the 1.4 kg ai ha^{-1} rate of ethalfluralin. It was thought that if the 1.4 kg ai ha^{-1} rate of ethalfluralin did not affect N_2-fixation, then the lower rates would not be of concern. This method acted as a comparison for the values determined for % Ndfa using the natural ^{15}N abundance method which was used only in 1995.

^{15}N isotope dilution calculations:

Ndfa was calculated (see Peoples *et al.*, 1989) as:

$$Ndfa = 100\ [\ 1 - (\text{atom }\%^{15}N_{sample} - 0.3663)/(\text{atom }\%^{15}N_{reference} - 0.3663)]$$

where Ndfa = the percentage of legume N fixed from atmospheric N_2, and 0.3663 represents the atom $\%^{15}N_{atmosphere}$.

Randomly selected 1.0 m^2 microplots within main plots were chosen early in the growing season (within 25 days after seeding) and marked with pin flags. Ammonium nitrate labeled with ^{15}N at 10.2 atom % ^{15}N was diluted in 10 litres of water and applied at a rate of 5 kg N ha^{-1} uniformly across the 1.0 m^2 microplot. After 15-20 minutes, the microplots were rinsed with water to prevent foliar uptake of the solution. In 1995, oat and in 1996 wheat from the weedy check were used as non-fixing reference crops. Just prior to crop harvest, samples consisting of four plants from the center of each microplot were cut at the base of the stem and dried. Plant samples were threshed and seed was collected. Shearer *et al.* (1980) determined that the total atom %^{15}N of the seed most accurately reflected the total atom %^{15}N of the whole plant. The seed was ground with a Cylotech 1093 sample mill then weighed in 6*4 mm tin capsules (Europa Scientific, Crewe, England). Sample sizes varied between 0.9-1.2 mg, the weight range required for accurate analysis in the mass spectrometer. Natural ^{15}N abundance samples were analyzed for atom % ^{15}N on a VG Micromass 602E isotope ratio mass spectrometer (Isotech, Middlewich, England). ^{15}N isotope dilution samples were analyzed for % ^{15}N on a continuous-flow isotope ratio mass spectrometer (CF-IRMS, Europa Scientific, Crewe, England) interfaced with a RoboPrep Sample Converter.

3.9.2 Natural ^{15}N Abundance Method

Randomly selected 1.0 m^2 microplots within main plots were chosen early in the growing season and marked with pin flags. When an enriched microplot existed in the same main plot, care was taken to ensure adequate spatial separation between microplots (at least 1.5 m). The same sampling procedure was used as for the enriched plots. The natural abundance plots were sampled prior to the enriched plots to minimize the possibility of contamination.

In 1995, a reference plant for the natural ^{15}N abundance method was not obtained at sampling time. Therefore, individual wheat seeds from the dockage sample were collected, ground and analyzed in the CF-IRMS to determine whether or not they were from one of the ^{15}N enriched microplots. A sample of 20 seeds from non-enriched plots in the experimental area was collected and a mean % atom ^{15}N value determined. This was used as the reference value for 1995 natural abundance %Ndfa calculations. In 1996, wheat from the weedy checks was used as the reference crop.

Natural ^{15}N abundance method calculations:

N_2-fixation was determined for all treatments at both locations in 1995 and 1996 using the natural ^{15}N abundance method. Percent Ndfa for the natural ^{15}N abundance approach was calculated (see Peoples *et al.*, 1989) as:

$$\text{Ndfa} = (\ \delta^{15}N_{cereal} - \delta^{15}N_{pulse} / \delta^{15}N_{cereal} - c)\ 100$$

where $\delta^{15}N = (\text{ atom }\%^{15}N_{sample} - 0.3663 / \text{atom }\%^{15}N_{atmosphere})\ 1000$ (Stevenson, 1996) and 'c' is the $\delta^{15}N$ value of N_2-fixing pea or lentil grown in N-free medium (Shearer and Kohl, 1986). A 'c' value of 0 (Bremer and van Kessel, 1990) for lentil and -1 (Peoples *et al.*, 1989) for pea were used in the calculations. In 1995 at Kernen, a large number of negative N_2-fixation values indicate some technical error likely occurred when determining the $\delta^{15}N$ value for the reference plant. Only the ^{15}N enrichment values were used from Kernen in 1995. Also, in 1996, % Ndfa values from the isotope dilution method were not reliable as many negative values for fixation occurred.

3.10 Economic Analysis

The objective of this part of the research was to determine which of the weed control treatments studied were the most agronomically and economically viable. The impacts of tillage, crop tolerance, weed control, and costs associated with herbicide application were assessed. The 1995 Farm Machinery Custom Rate and Rental Guide (Saskatchewan Agriculture and Food, 1995a) and the 1995 Manufacturer's List for Retail Herbicide Costs (Saskatchewan Agriculture and Food, 1995b) were used to calculate the cost of the herbicides, their application and incorporation. Those treatments that provided acceptable weed control and exhibited excellent crop tolerance were ranked from lowest to highest cost.

4.0 RESULTS

4.1 Lentil

4.1.1 Wild Oat Control

Wild oat populations at Kernen and Goodale were greater in 1995 than in 1996 (Appendix Table A2.1). In 1995, wild oat control, as determined by visual assessment, was excellent for preplant surface application and shallow incorporation of ethalfluralin and triallate/trifluralin (10:4) at Kernen, but not at Goodale due to higher wild oat pressure (data not presented). Visual ratings of wild oat control at 40 DAS at Goodale indicated unacceptable control with surface applied ethalfluralin at 0.84 kg ai ha^{-1}, but shallow incorporation of the same rate increased control to above minimum acceptable levels. At 53-56 DAS at Goodale, control of wild oat was also unacceptable when ethalfluralin was surface applied at 0.84 kg ai ha^{-1} (applied in combination with fall metribuzin or spring glyphosate) or 1.1 kg ai ha^{-1} (applied in combination with fall metribuzin). At 53-56 DAS at Kernen wild oat control was excellent for all treatments.

Wild oat biomass data for 1995 and 1996 indicate no significant difference in control among ethalfluralin rates, surface or shallow incorporation, ethalfluralin and glyphosate compared to ethalfluralin and metribuzin or finally, between surface and shallow incorporation of triallate/trifluralin (10:4) compared to ethalfluralin at 1.1 kg ai ha^{-1} (Appendix Table A2.1). Conventional incorporation of ethalfluralin did not decrease wild oat biomass compared to the same rate surface applied or shallowly incorporated.

Biomass and visual rating data indicate that acceptable control of wild oat can be obtained with surface application and shallow incorporation of ethalfluralin and triallate/trifluralin (10:4) at rates equivalent to or greater than 1.1 and 1.96 kg ai ha^{-1}, respectively. High populations of wild oat can be controlled with a surface application of ethalfluralin at a rate of 1.4 kg ai ha^{-1}.

4.1.2 Green Foxtail Control

Green foxtail control in lentil was excellent in all ethalfluralin and triallate/trifluralin (10:4) herbicide treatments as determined by visual assessments (data not presented) and dry weight biomass reduction (Table 4.1). Control remained above the acceptable level of 80% at all dinitroaniline rates and types of application at both locations in both years and both rating dates. The high level of control at all rates indicates that green foxtail is more susceptible than wild oat to surface applied or shallowly incorporated ethalfluralin. Dry weight biomass of green foxtail was lower than the untreated weedy check in all treatments in all four experiments with the exception of Kernen in 1996 (Table 4.1) where the green foxtail population was very low. No contrasts were calculated as the data indicate excellent control in all dinitroaniline-treated plots.

Table 4.1 Green foxtail biomass 60-75 DAS[z] following various herbicide treatments in lentil at Kernen and Goodale, 1995 and 1996.

Treatment Fall	Treatment Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	Application method[y] Spring	Green foxtail biomass (dry weight g m^{-2}) Kernen 1995	Kernen 1996	Goodale 1995	Goodale 1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	1	0.1	1	1
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	0	0	0	1
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	1	0.4	0	1
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		1	0.3	2	1
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		0	0	2	0
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		0	0	0	0
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	1	0	1	0
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	1	0.3	3	4
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	0	0.8	1	1
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	1.6	0	7
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		0	0	1	0
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		0	0	0	1
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		0	0	1	1
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	1	0.2	4	0
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	0	0	0	1
Ethalfluralin	Tillage + Metribuzin	1.1/0.21	PpI	PoE	0	0.6	0	0
None	Glyphosate	0.27		Burn off	6	0.1	12	6
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	7	0.7	0	0
None	Tillage				49	1.5	30	19
LSD (0.05)					5	1.1	5	7

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

4.1.3 Volunteer Wheat Control

Volunteer wheat control was determined by visual control ratings at Kernen and Goodale in 1995 and at Kernen only in 1996. Volunteer wheat weed pressure was low. Dry weight biomass data were collected in 1996, but populations were sparse and so visual control ratings are more indicative of weed control. In 1995, visual assessment at 54-56 DAS indicated acceptable control in all ethalfluralin and triallate/trifluralin(10:4) treatments at both locations. Control of volunteer wheat was not affected by ethalfluralin rate or incorporation level. Higher weed pressure may have shown some differences in weed control, especially among the rates of ethalfluralin.

In 1996 at Kernen, visual assessment of volunteer wheat control indicated a slight reduction in control when ethalfluralin was combined with fall-applied metribuzin compared to when ethalfluralin was applied in combination with a spring burn-off treatment of glyphosate (Table 4.2). This indicates that the pre-seeding burn-off treatment with glyphosate may have contributed to the improved volunteer wheat control. In 1996, the glyphosate burn-off treatment provided 66% control of volunteer wheat compared to only 8% in 1995. Heavier weed pressure in 1996 may have contributed to reduced control of volunteer wheat in the dinitroaniline-treated plots, or perhaps dinitroaniline herbicide activity was reduced due to low soil temperatures. The cool spring may have delayed ethalfluralin activation beyond germination of the volunteer wheat.

Table 4.2 Percentage control 54-56 DAS[z] of volunteer wheat following various herbicide treatments in lentil at Kernen, 1995 and 1996 and Goodale, 1995.

Treatment		**Rate (kg ai ha^{-1})**	**Application method[y]**		**Control (%)**		
					Kernen		**Goodale**
Fall	Spring	Fall / Spring	Fall	Spring	1995	1996	1995
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	94	88	80
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	93	90	100
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	99	88	100
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		95	81	95
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		95	71	98
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		99	70	95
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	98	80	100
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	93	94	90
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	98	90	96
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	95	80	98
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		99	65	98
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		94	73	98
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		95	71	98
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	98	88	98
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	94	84	90
Ethalfluralin	Tillage + Metribuzin	1.1/0.16	PpI	PoE	85	79	85
None	Glyphosate	0.27		Burn off	8	66	3
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	23	60	98
None	Tillage				0	0	0

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Glyphosate application in 1995 was too early to control volunteer wheat. In 1996 however, volunteer wheat seedlings were present at the time of glyphosate application and some control from glyphosate was achieved.

The triallate/trifluralin (10:4) treatment resulted in excellent control of volunteer wheat in all four experiments (Table 4.2). Triallate/trifluralin (10:4) is registered for weed control in wheat but the wheat must be seeded below the treated layer to prevent crop injury. The glyphosate likely contributed to the high level of volunteer wheat control, but as the wheat seeds were in the same layer as the triallate/trifluralin (10:4), the trifluralin may have had some activity on the wheat due to the lack of a physical soil barrier between the wheat seeds and the herbicide. Triallate may also partially control the wheat when the herbicide and wheat are both in the surface layer of soil. These findings are in accordance with those of Kirkland (1994), who observed a reduction in wheat yield with non-incorporated triallate.

4.1.4 Broadleaf Weed Control

The effect of herbicide treatment on broadleaf weed biomass is presented in Table 4.3. Visual control ratings are also presented for the major broadleaf weeds present (Appendix Table A2.2). Three of the four experiments received the same treatments, but non-homogeneous variances prevented a combined analysis of the experiments. Data are presented individually for years and locations.

Table 4.3 Broadleaf weed biomass 60-77 DAS[z] following various herbicide treatments in lentil at Kernen and Goodale, 1995 and 1996.

Treatment		Rate	Application method[y]		Broadleaf weed biomass (dry weight g m^{-2})			
		(kg ai ha^{-1})			Kernen		Goodale	
Fall	Spring	Fall / Spring	Fall	Spring	1995	1996	1995	1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	27	5	23	14
Ethalfluralin	Glyphosate	1.1/.27	PpSA	Burn off	0	18	6	22
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	8	8	15	6
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		11	28	14	40
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		1	39	27	40
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		9	38	43	19
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	2	15	17	11
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	1	3	18	5
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	6	9	8	6
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	19	5	6	5
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		14	109	38	24
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		29	114	34	34
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		10	211	32	27
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	12	3	11	6
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	0	0	0	9
Ethalfluralin	Tillage + Metribuzin	1.1/0.16	PpI	PoE	1	1	21	8
None	Glyphosate	0.27		Burn off	59	38	53	31
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	18	10	3	6
None	Tillage				60	70	96	25
LSD (0.05)					32	56	38	23
Contrasts :								
Ethalfluralin rates					NS	NS	NS	NS
Ethalfluralin surface application vs shallow incorporation					NS	**	NS	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin					NS	**	*	**
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS	NS

*, **, NS Significant at the 0.05, 0.01 level of probability and not significant, respectively.

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Broadleaf weed biomass in lentil at 8-11 weeks after seeding indicates that surface application of ethalfluralin provided weed control equivalent to that provided by shallow incorporation of ethalfluralin in three of the four experiments (Table 4.3). Surface application compared to shallow incorporation of ethalfluralin provided enhanced weed control at Kernen in 1996. Most notably, the combination of ethalfluralin, a glyphosate burn-off treatment and a post-emergence application of metribuzin provided greater total broadleaf weed control than ethalfluralin and fall-applied metribuzin.

Ethalfluralin rates did not significantly affect broadleaf weed control in any of the four experiments (Table 4.3). Conventional incorporation of ethalfluralin did not enhance broadleaf weed control compared to the average of the same rate surface applied or shallowly incorporated.

In 1996 at Kernen, fall-applied metribuzin resulted in very little control of stinkweed and volunteer canola when surface applied and next to no control when shallowly incorporated as determined by visual control ratings (Appendix Table A2.2) and broadleaf weed biomass (Table 4.3). Broadlef weed control with fall-applied metribuzin was significantly poorer than with a glyphosate burn-off treatment followed by a post-emergent application of metribuzin at 0.16 kg ai ha^{-1} in three of the four experiments (Table 4.3). The trend in the fourth experiment was towards reduced control as well, even though the differences were not significant. Stinkweed populations at Goodale in 1995 were sufficient to obtain visual ratings to further show the reduced weed control from fall compared to spring metribuzin treatments (Appendix Table A2.2).

Control of wild buckwheat was assessed visually at both locations in 1996. Based on rates of ethalfluralin in combination with a spring burn-off treatment with glyphosate, weed control was better at Kernen than at Goodale. Wild buckwheat was surface applied in the spring at Kernen, while none was applied at Goodale where the indigenous wild buckwheat population was relied upon. The conditions at Kernen more likely reflected those of a direct seeding system and reduced tillage. More seeds were on the soil surface and were controlled by the ethalfluralin, rather than escaping control by emerging from below the treated layer.

Control of kochia at Kernen in 1996 was reduced with surface or shallow incorporation of ethalfluralin compared to conventional incorporation (Appendix Table A2.2). This indicates that either a higher rate of ethalfluralin is needed to control kochia if it is not incorporated or that incorporating the ethalfluralin is a much more effective treatment. While kochia control was not acceptable under reduced incorporation of ethalfluralin, control with a surface application was greater than with a shallow incorporation.

With the exception of the glyphosate burn-off, control of lamb's-quarters exceeded 60% with most herbicide treatments at Goodale in 1995 (Appendix Table A2.2). Lamb's-quarters was controlled by either metribuzin or ethalfluralin. Control was usually enhanced by increasing the rate of ethalfluralin and also by a glyphosate burn-off treatment followed by a post-emergent metribuzin treatment as opposed to a fall metribuzin treatment (Appendix Table A2.2).

4.1.5 Lentil Tolerance

4.1.5.1 Emergence

Lentil emergence in 1995 was much slower than in 1996 due to cooler temperatures during germination and emergence (Appendix Table A3.1). Herbicides had no effect on lentil emergence at 11-13 DAS; tillage, however, did affect lentil emergence. At 11-13 DAS, in each year, lentil seedlings emerged earlier in the rotary harrowed than in the same herbicide treatments with no incorporation (Appendix Table A3.1). However, the difference was not significant when the data were combined over years (Appendix Table A3.4). It is evident that shallow tillage speeds up lentil emergence early in the season. Where ethalfluralin was applied at 1.1 kg ai ha^{-1}, lentil emerged more rapidly in conventionally tilled plots than in plots that received either shallow tillage or no tillage. This indicates that the crop emergence rate increases as the degree of tillage increases.

Neither glyphosate burn-off, fall applied metribuzin nor ethalfluralin at any rate tested had any effect on lentil emergence 11-13 DAS (Appendix Tables A3.1 and A3.4). Likewise, lentil emergence was not affected by treatment with triallate/trifluralin (10:4) or ethalfluralin at the recommended rate of 1.1 kg ai ha^{-1} when surface application and shallow incorporation data were combined.

Herbicide treatment did not affect the rate of lentil emergence when assessed 17 DAS (Appendix Tables A3.2 and A3.5); however, at 17 DAS, lentil emergence was still slower in untilled herbicide treated plots compared to plots that received shallow tillage.

Lentil did not emerge more rapidly in the conventionally-tilled plots compared to the shallow and surface-applied plots when data were combined over locations in either year. The effect of conventional incorporation on lentil emergence that was apparent at 11-13 DAS had dissipated by 17 DAS (Appendix Table A3.2).

Herbicide or tillage had no effect on lentil stand at 23-26 DAS and no significant treatment differences or interactions between treatments were detected (Appendix Tables A3.4 and A3.6). Any tillage effects on crop emergence were no longer apparent at 23-26 DAS, indicating that while lentil emergence was delayed initially in the no tillage plots, the delay was no longer apparent 3-4 weeks after seeding (Table 4.4).

Analysis of variance on lentil emergence at 11-13 and 17-18 DAS indicated that years was a highly significant source of variation (Appendix Tables A3.4 and A3.5). Years*treatments interaction was significant at 11-13 DAS and at 17-18 DAS. Temperature at crop emergence was greater in 1996 than 1995 and contributed to the faster rate of emergence in 1996, resulting in this interaction. Lentil plant stand means are presented individually for years for both of these times as well as a mean value for the years (Appendix Table A3.1 and A3.2)

4.1.5.2 Tolerance

Lentil exhibited excellent tolerance to the herbicide treatments as determined by visual assessment 40-43 DAS in both years at both locations (Table 4.5). By the second rating

Table 4.4 Lentil plant stand 23-26 DAS[z] at Kernen and Goodale, 1995 and 1996.

Treatment		**Rate** (kg ai ha^{-1})	**Application method**[y]		**Lentil stand** (plants m^{-2})
Fall	Spring	Fall / Spring	Fall	Spring	Mean
Ethalfluralin	Glyphosate	0.84/0.27	PpSA	Burn off	141
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	133
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	135
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		142
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		145
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		139
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	142
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	146
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	144
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	144
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		146
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		142
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		142
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	138
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.46	PpI	PoE	143
Ethalfluralin	Tillage + Metribuzin	1.1/0.21	PpI	PoE	136
None	Glyphosate	0.27		Burn off	143
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	144
None	Tillage				138
LSD (0.05)					NS

NS Not significant.
[z] Days after seeding.
[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.
[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

date (54-56 DAS) lentil had recovered from the slight injury noted at 40-43 DAS.

Table 4.5 Percentage crop injury 40-43 DAS[z] and seed yield of lentil following various herbicide treatments in lentil, mean for Kernen and Goodale, 1995 and 1996.

Treatment Fall	Treatment Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	Application method[y] Spring	Injury (%) Mean	Seed yield (kg ha^{-1}) Mean
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	4	2220
Ethalfluralin	Glyphosate	1.1/.27	PpSA	Burn off	5	2110
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	3	2310
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		3	2190
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		4	2200
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		4	2190
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	4	2270
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	3	2410
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	3	2440
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	3	2330
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		4	2120
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		2	2090
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		3	2140
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	2	2260
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	1	2550
Ethalfluralin	Tillage + Metribuzin	1.1/0.21	PpI	PoE	2	2560
None	Glyphosate	0.27		Burn off	2	2020
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	4	2100
None	Tillage				0	1880
LSD (0.05)					-	310
Contrasts:						
Ethalfluralin rates					-	NS
Ethalfluralin PpSA vs PpSI					-	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin					-	**
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					-	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					-	**

**, NS Significant at the 0.01 level of probability and not significant, respectively.

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

4.1.5.3 Seed Yield

The weed management strategy used in lentil varied slightly, depending on the weed population present. In 1995, the lentil experiment at Kernen did not receive a post-emergent application of metribuzin on those plots receiving a glyphosate burn-off treatment because of insufficient weed population. The other three experiments were treated equally. Bartlett's test for homogeneity of variances indicated homogeneous error variances and all four experiments were combined for analysis (Table 4.5). The combined analysis indicated significant treatment differences. The untreated weedy check yielded the lowest, indicating weed control strategies were contributing to increased seed yield. Contrasts on the combined yield analysis indicated some significant differences. Higher lentil yields resulted from fall-applied ethalfluralin in combination with a spring glyphosate burn-off treatment and post-emergent metribuzin at 0.16 kg ai ha^{-1} compared to fall-applied ethalfluralin and metribuzin. Conventional incorporation of ethalfluralin resulted in a higher lentil yield than the mean of the surface applied and shallowly-incorporated ethalfluralin (all 1.1 kg ai ha^{-1}) applied in combination with a glyphosate burn-off and post-emergent metribuzin.

However, the 1.4 kg ai ha^{-1} rate of ethalfluralin, surface applied and the 1.1 kg ai ha^{-1} rate of ethalfluralin shallowly incorporated resulted in yields equivalent to the standard treatment of 1.1 kg ai ha^{-1} of ethalfluralin conventionally incorporated. Lentil yield was not affected by ethalfluralin rate, nor did the surface application of ethalfluralin yield differently from the shallow incorporation of ethalfluralin.

4.1.6 N_2-fixation

4.1.6.1 ^{15}N Isotope Dilution Method

N_2-fixation in lentil, as determined by the ^{15}N isotope dilution method, was higher at Kernen than at Goodale (Table 4.6). At Kernen in 1995, N_2-fixation values ranged between 40 and 66%, whereas at Goodale, values ranged from 8% in the surface-applied ethalfluralin + glyphosate pre-seeding burn-off treatment to 63% in the untreated weedy check. Data for 1996 (^{15}N isotope dilution method) are not presented due to a large number of negative values and inconsistency among replications. At Goodale in 1995, reduced fixation was likely due to a non-vigourous lentil stand, attributable to herbicide injury to the root and shoot, as well as dry environmental conditions. High fixation values in the check and the glyphosate burn-off treatment are likely due to increased competition for nitrogen because of higher weed competition in these plots.

4.1.6.2 Natural ^{15}N Abundance Method

In 1995 at Kernen, N_2-fixation values in lentil were negative. These values for % Ndfa at Kernen were unreliable due to technical error and, thus, are not included. This was not the case at Goodale, however.

Table 4.6 Percentage N_2 derived from the atmosphere by lentil, as determined by ^{15}N isotope dilution method following various herbicide treatments at Kernen and Goodale, 1995.

Treatment		**Rate** (kg ai ha^{-1})	**Application method**[z]	**% Ndfa**	
Fall /	Spring	Fall / Spring	Fall / Spring	Kernen	Goodale
Ethalfluralin	Glyphosate[y]	1.4 / 0.27	PpSA / burn off	66	8
Ethalfluralin + Metribuzin	None	1.4 + 0.36[x]	PpSA	42	14
Ethalfluralin	Glyphosate	1.4 / 0.27	PpSI / burn off	62	23
Ethalfluralin + Metribuzin	None	1.4 / 0.36	PpSI	43	17
None	Glyphosate	0.27	Burn off	40	43
None	Tillage			51	63
LSD (0.05)				NS	25

[z] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[y] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} at Goodale in 1995.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Goodale results for 1995 and 1996 results for both locations are presented (Table 4.7). In 1995 at Goodale, triallate/trifluralin (10:4) shallowly incorporated and 1.4 kg ai ha^{-1} ethalfluralin shallowly incorporated and surface applied significantly reduced N_2-fixation compared to the untreated check. In 1996, some differences in N_2-fixation among treatments existed, especially among the untreated check and herbicide treatments, however N_2-fixation in lentil was not reduced by reduced incorporation of the herbicides.

Table 4.7 Percentage N_2 derived from the atmosphere by lentil as determined by the natural ^{15}N abundance method following various herbicide treatments at Goodale in 1995 and at Kernen and Goodale in 1996.

Treatment		Rate (kg ai ha^{-1})	Application method[z]		% Ndfa		
					1995	1996	
Fall	Spring	Fall / Spring	Fall	Spring	Goodale	Kernen	Goodale
Ethalfluralin	Glyphosate[y]	0.84/0.27	PpSA	Burn off	61	43	55
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	53	43	55
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	40	48	56
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		46	53	78
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		41	47	57
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		32	51	64
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	47	48	56
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	46	36	62
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	45	52	61
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	47	49	56
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		49	52	65
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		44	53	65
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		30	55	73
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	36	47	56
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	42	36	52
Ethalfluralin	Tillage + Metribuzin	1.1/0.16	PpI	PoE	49	45	53
None	Glyphosate	0.27		Burn off	41	56	58
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	47	53	62
None	Tillage				59	60	55
LSD (0.05)					19	16	20

[z] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[y] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

4.2 Pea

4.2.1 Wild Oat Control

Wild oat populations at Kernen and Goodale were higher in 1995 than in 1996. Wild oat control, as determined by visual assessment in pea, was identical to that for lentil (data not presented) (See Section 4.1.1).

In 1996, no significant differences in wild oat biomass were present among the treatments (Appendix Table A2.3). At Kernen in 1995, all treatments, with the exception of the glyphosate burn-off treatment and glyphosate plus a late application of sethoxydim, resulted in wild oat dry weights below 1 g m^{-2}. Significant differences occurred in wild oat biomass, but only among those treatments where dinitroaniline herbicides were not applied and, thus, wild oat was not controlled. In 1995, at Goodale, all herbicide-treated plots had a lower wild oat biomass than the untreated check, however, contrasts on wild oat biomass indicated no significant differences among any of the other comparisons, except for the glyphosate treatment.

4.2.2 Green Foxtail Control

Green foxtail control in pea was excellent in all ethalfluralin and triallate/trifluralin (10:4) herbicide treatments, as determined by visual assessments and dry weight biomass reduction. Dry weight biomass of green foxtail was lower than the untreated weedy check in all treatments in all four experiments (Table 4.8). As with lentil, no

Table 4.8 Green foxtail biomass 60-76 DAS[z] following various herbicide treatments in pea at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Green foxtail biomass (dry weight g m^{-2}) Kernen 1995	Kernen 1996	Goodale 1995	Goodale 1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	0	0.4	1	0.6
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	0	0.1	0	0.5
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	0	0	2	0.3
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		1	0.1	0	0.6
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		0	0	1	0.2
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		0	0	0	0.1
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	1	0	0	0.1
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	0	0.3	2	0.7
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	0	0.2	0	0.6
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	0.3	0	0.3
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		0	0	0	0.3
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		0	0	0	0.1
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		0	0	0	0.2
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	0	0.3	3	0.0
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36 / 0.46	PpI	PoE	0	0.2	0	0.9
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	0	0	0	1.1
None	Glyphosate	0.27		Burn off	4	0.4	8	3.3
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[v]	0.27 + 0.2		Burn off + PoE	4	0.5	1	0
None	Tillage				22	0.8	14	6.2
LSD (0.05)					4	0.5	3	1.2

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent MCPA- Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[v] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

contrasts were calculated as data indicates excellent control in all dinitroaniline herbicide-treated plots.

4.2.3 Volunteer Wheat Control

Volunteer wheat control was determined by visual control ratings at Kernen and Goodale in 1995 and at Kernen only in 1996. Visual control of volunteer wheat was determined for the entire treated plot and not individually between pea and lentil. Wheat control ratings for pea are, thus, the same as the wheat control ratings in lentil (See Section 4.1.3) with the exception of the imazamox/imazethapyr (240 g L^{-1} SN) (1:1) treatment in pea which was substituted for sethoxydim plus metribuzin (both applied post-emergence) in lentil. Imazamox/imazethapyr (1:1) controlled volunteer wheat to a level of 98% (as determined by visual assessment 56 DAS) at Goodale in 1995. At Kernen in 1996, volunteer wheat was controlled to a level of 88% (as determined by visual assessment 56 DAS). No volunteer wheat was present in the plots at Goodale in 1996.

4.2.4 Broadleaf Weed Control

Bartlett's test for homogeneity of variances indicated that broadleaf weed biomass data for 1996 could be combined for analysis ($\chi_2 =$ 0.85 with 1 df < 3.84 at the 0.05 level of probability).

In 1995, broadleaf weed biomass was reduced by all herbicide treatments when compared to the untreated weedy check (Table 4.9). In 1996, however, weed biomass was greater than or equivalent to the untreated check in plots receiving the glyphosate burn-off treatment or ethalfluralin at 0.84 kg ai ha^{-1} and 1.4 kg ai ha^{-1} applied in combination with fall-applied metribuzin. Uneven weed population and pressure across the experiment may have contributed to increased weed biomass with these herbicide treatments. Contrasts on broadleaf weed biomass showed no significant differences between ethalfluralin rates or degree of incorporation. A conventional incorporation of ethalfluralin did not significantly improve broadleaf weed control when compared to the mean of the broadleaf weed control values obtained from the surface application and shallow incorporation at 1.1 kg ai ha^{-1} of ethalfluralin.

At Goodale in 1995, and Kernen and Goodale in 1996, broadleaf weed biomass was significantly reduced by ethalfluralin plus a glyphosate burn-off followed by a post-emergence application of MCPA-Na salt (at 0.8 kg ai ha^{-1} in 1995 and 0.46 kg ai ha^{-1} in 1996) compared to ethalfluralin and fall-applied metribuzin (Table 4.9).

4.2.5 Pea Tolerance

4.2.5.1 Emergence

Pea emergence 11-13 DAS, like lentil, was increased by shallow and conventional tillage (Appendix Tables A3.3 and A3.4). Herbicides had no effect on pea emergence at

Table 4.9 Broadleaf weed biomass 67-76 DAS[z] following various herbicide treatments in pea at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Broadleaf weed biomass (dry weight g m^{-2}) 1995 Kernen	1995 Goodale	1996 Mean
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	6	2	3
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	4	1	3
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	2	1	3
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		2	9	20
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		0	9	17
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		2	11	27
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	10	1	2
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	11	1	3
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	3	0	5
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	0	6
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		4	23	33
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		12	18	22
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		1	10	43
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	3	1	3
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	2	0	1
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	0	0	7
None	Glyphosate	0.27		Burn off	7	32	33
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[v]	0.27 + 0.2		Burn off + PoE	7	2	4
None	Tillage				38	51	33
LSD (0.05)					15	18	19
Contrasts:							
Ethalfluralin rates					NS	NS	NS
Ethalfluralin surface application vs shallow incorporation					NS	NS	NS
Ethalfluralin + glyphosate PpSA and PpSI vs ethalfluralin PpSA and PpSI + metribuzin					NS	**	**
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent MCPA- Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[v] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

11-13 DAS. In 1996, at 11-13 DAS, pea emergence was more advanced in the shallowly and conventionally tilled plots; in 1995 conventional tillage increased pea emergence compared to the mean of pea emergence in shallowly incorporated and surface applied plots (Appendix Table A3.3). However, none of the differences in pea emergence, other than the tillage effect, was significant when averaged over years and locations. Neither herbicide nor tillage affected pea emergence at 17-18 DAS (Table 4.10). By 17-18 DAS, any early tillage affect on pea emergence was no longer evident. Differences in pea plant stand were not different at 23-26 DAS (data not presented).

A combined analysis of variance on pea emergence at three dates (Appendix Tables A3.7, A3.8 and A3.9) indicated significant treatment differences and significant year*treatment interaction at 11-13 DAS only. This indicates that treatment effects at 11-13 DAS were influenced by the effects of the year. Treatment means for each year are presented for 11-13 DAS (Appendix Table A3.3). These significant differences in pea emergence were dissipated at 17-18 or 23-26 DAS (Appendix Tables A3.8 and A3.9). Years and the year*location interaction were significant at 17-18 DAS (Appendix Table A3.8). This was attributed to differences in weather conditions at the time of crop germination and emergence between the two years. As the year*treatment interaction was not significant at 17-18 DAS (Appendix Table A3.8), treatment means were averaged across years and locations (Table 4.10).

Table 4.10 Treatment means for pea stand density 17-18 DAS[z] following various herbicide treatments at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate ($kg\ ai\ ha^{-1}$) Fall / Spring	Application method[y] Fall	/ Spring	Pea stand ($plants\ m^{-2}$) Mean
Ethalfluralin	Glyphosate	0.84/0.27	PpSA	Burn off	44
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	46
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	47
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		49
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		48
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		48
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	51
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	55
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	48
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	54
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		54
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		54
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		51
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	56
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	61
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	60
None	Glyphosate	0.27		Burn off	50
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[w]	0.27 + 0.2		Burn off + PoE	44
None	Tillage				57
LSD (0.05)					NS

NS Not Significant

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[w] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

4.2.5.2 Tolerance

Differences in pea tolerance to herbicide treatments were noted (Table 4.11). All spring glyphosate treatments (with the exception of the glyphosate burn-off treatment alone) were followed by a post-emergent application of MCPA-Na salt, except at Kernen in 1995. Pea tolerance to post-emergent application of MCPA-Na salt was not acceptable according to the ECW standard of 10% allowable injury at all but Kernen in 1995. In 1995 at Kernen, MCPA-Na salt was applied to the two conventional incorporation treatments. In 1995 at Kernen, all injury ratings at 40-43 DAS remained below the maximum acceptable level of 10%. This indicates that surface applied and shallowly incorporated ethalfluralin treatments are not adversely affecting pea crop tolerance as determined by a visual assessment.

At Goodale in 1995, a heavy broadleaf weed population justified the post-emergent application of MCPA-Na salt to all treatments which had received a glyphosate burn-off treatment and the two conventional incorporation ethalfluralin treatments. The recommended rate of 0.46 kg ai ha^{-1} was accidently exceeded and 0.8 kg ai ha^{-1} MCPA-Na salt was applied. Significant crop injury resulted, as determined by visual injury ratings 40-43 DAS (Table 4.11). Injury appeared to be most severe in those treatments where pea was seeded into the surface application or shallow incorporation treatments of ethalfluralin; less pea injury was noted in the conventionally tilled treatments. Reduced injury in the conventionally incorporated treatments may have been a result of greater plant biomass at time of herbicide application, leading to a visual assessment value

Table 4.11 Percentage injury to pea plants 40-43 DAS[z] following various herbicide treatments at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Pea injury (%) Kernen 1995	Kernen 1996	Goodale 1995	Goodale 1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	1.5	8	74	15
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	0.5	7	79	18
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	1.0	9	78	8
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		1.0	5	4	1
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		2.5	4	3	7
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		1.5	3	5	7
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	2.5	8	79	13
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	1.5	6	78	11
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	0.5	6	81	12
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	5	78	10
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		0.5	2	3	2
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		1.5	1	4	1
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		1.0	2	2	1
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	1.5	5	78	10
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	0.5	3	68	7
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	6.5	3	65	8
None	Glyphosate	0.27		Burn off	1.0	4	4	3
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[v]	0.27 + 0.2		Burn off + PoE	1.5	2	4	2
None	Tillage				0	0	0	0

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent MCPA- Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[v] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

indicating lower injury. By 53-56 DAS, pea had partially recovered from the initial injury but levels of injury still exceeded 10% (data not presented). Favorable growing conditions throughout August resulted in continued recovery of the peas and seed yield, was not reduced as a result of this injury when compared to no post-emergent MCPA-Na salt application as indicated by contrasts (Section 4.2.5.3). Some differences among individual treatments were significant, however.

In 1996, all spring glyphosate treatments received post-emergent applications of MCPA-Na salt at the recommended rate of 0.46 kg ai ha^{-1}. Cool conditions at the time of application at Goodale resulted in increased crop injury; some treatments exceeded the acceptable injury level of 10% (Table 4.11). At Kernen, herbicide application occurred under warmer conditions, crop tolerance was enhanced, and the injury ratings remained below 10% in all MCPA-Na salt treatments. At the second visual assessment date (53-56 DAS), the injury at both locations was below 10% for all treatments (data not presented).

4.2.5.3 Seed Yield

Pea seed yield was determined for each of the four experiments. Bartlett's test for homogeneity of variances was performed and acceptance of homogeneous error variances was made ($\chi2$ = 3.33 with 1 df < 3.84 at the 0.05 level of probability). However, only 1996 seed yield data for the two locations were combined for analysis.

In 1995 at Goodale and Kernen and in the 1996 combined analysis, contrasts indicated no significant differences in pea yield among the comparisons (Table 4.12) other than some of the treatments yielded higher than the tilled check treatment and one or two other treatments.

4.2.6 N_2-fixation

4.2.6.1 ^{15}N Isotope Dilution Method

Differences among treatments were not significant at either location in 1995 (Table 4.13). The % Ndfa values, based on ^{15}N isotope dilution, were quite variable, and consequently, seemingly large differences were not significant.

The % Ndfa values at Goodale were consistently lower than those at Kernen in 1995 (Table 4.13). Above ground pea plant growth at Goodale in 1995 was poor, likely an indication of a weak root system which is not conducive to efficient N_2-fixation. Poor plant growth may have been due to the dry conditions and low water holding capacity of the sandy loam soil resulting in water stress on the plants. In addition, the post-emergent application of 0.8 kg ai ha^{-1} MCPA-Na salt (a high rate) at Goodale in 1995 severely decreased pea N_2-fixation compared to similar plots at Kernen with no MCPA-salt. However, treatments which did not include post-emergent MCPA-Na salt at Goodale also resulted in low N_2-fixation. One possible explanation is that the fall applied metribuzin may have been causing some harm to the plant and inhibited N_2-fixa-

Table 4.12 Seed yield of pea following various herbicide treatments at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[z] Fall	/ Spring	Seed yield (kg ha^{-1}) 1995 Kernen	1995 Goodale	1996 Mean
Ethalfluralin	Glyphosate[y]	0.84/0.27	PpSA	Burn off	4440	1650	3100
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	4720	1740	3210
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	4650	1680	3295
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		4730	1880	3405
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		4820	2120	3260
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		4980	2050	3430
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	4880	1700	3440
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	4740	1640	3570
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	4690	1670	3555
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	4820	1810	3125
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		4710	1660	3135
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		4890	2020	2970
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		4890	1920	3240
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	4510	1560	3565
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	4860	1740	3390
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	4810	1800	3195
None	Glyphosate	0.27		Burn off	4370	1790	3285
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[w]	0.27 + 0.2		Burn off + PoE	4570	1990	3360
None	Tillage				4360	1640	2730
LSD (0.05)					520	390	395
Contrasts:							
Ethalfluralin rates					NS	NS	NS
Ethalfluralin PpSA vs ethalfluralin PpSI					NS	NS	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin (fall)					NS	NS	NS
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS

[z] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.
[y] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent MCPA- Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.
[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.
[w] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

tion. This trend was also seen in lentil at Goodale in 1995, when metribuzin was applied in the fall.

Table 4.13 Percentage N_2 derived from the atmosphere by pea, as determined by ^{15}N isotope dilution method following various herbicide treatments at Kernen and Goodale, 1995.

Treatment		**Rate** (kg ai ha^{-1})	**Application method**[z]	**% Ndfa**	
Fall /	Spring	Fall / Spring	Fall / Spring	Kernen	Goodale
Ethalfluralin	Glyphosate[y]	1.4 / 0.27	PpSA / burn off	58	3
Ethalfluralin + Metribuzin	None	1.4 + 0.36[x]	PpSA	46	9
Ethalfluralin	Glyphosate	1.4 / 0.27	PpSI / burn off	58	7
Ethalfluralin + Metribuzin	None	1.4 / 0.36	PpSI	22	12
None	Glyphosate	0.27	Burn off	35	20
None	Tillage			28	34
LSD (0.05)				NS	NS

[z] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.
[y] Spring glyphosate treatments were followed by post-emergent MCPA-Na salt at 0.46 kg ai ha^{-1} at Kernen and 0.8 kg ai ha^{-1} at Goodale.
[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

While significant differences did not exist among treatments, some trends did exist. Fall-applied metribuzin reduced N_2-fixation below that in the untreated check in the shallowly incorporated ethalfluralin treatment and both this treatment and the surface-applied metribuzin plus ethalfluralin resulted in lower fixation values than the ethalfluralin applied alone in the fall. At Kernen, all herbicide treated plots, with the exception of the metribuzin and ethalfluralin at 1.4 kg ai ha^{-1} fall applied and shallowly incorporated, resulted in N_2-fixation values greater than the untreated weedy check. This indicates that some adverse effect on N_2-fixation may result from fall-applied metribuzin as opposed to ethalfluralin plus the glyphosate burn-off application.

4.2.6.2 Natural ^{15}N Abundance Method

N_2-fixation in pea determined by the natural ^{15}N abundance method indicated some significant differences among the treatments at Goodale in 1995 (Table 4.14). Values at Goodale varied between 18% Ndfa in the ethalfluralin at 1.4 kg ai ha^{-1} surface applied in combination with a spring burn-off treatment with glyphosate followed by MCPA-Na salt at 0.8 kg ai ha^{-1} to 46% Ndfa in the glyphosate burn-off treatment. This indicates that glyphosate and its metabolites did not adversely affect N_2-fixation in pea when applied as a pre-seeding burn-off. 1995 Goodale data also indicate that reductions in N_2-fixation were not associated with reduced incorporation of ethalfluralin, the 1.1 kg ai ha^{-1} rate of ethalfluralin did not produce a significant effect when tillage systems were compared.

In 1996 at Kernen, N_2-fixation in pea, as determined by the natural ^{15}N abundance method, ranged from 36% to 56% (Table 4.14). ANOVA indicated no significant differences among the treatments other than for the tilled check. N_2-fixation was highest in the untreated check, likely due to the competition with weeds for nitrogen, thus forcing the pea plants to derive more of their nitrogen from the atmosphere as opposed to the soil. In 1996 at Goodale, N_2-fixation values were similar to those at Kernen, ranging from 40 to 60%. Only four of the treatments resulted in N_2-fixation values lower than the highest N_2-fixing treatment: ethalfluralin at 1.4 kg ai ha^{-1} plus metribuzin applied in the fall, shallowly incorporated. Only two treatments, ethalfluralin at 1.4 kg ai ha^{-1} and

Table 4.14 Percentage N_2 derived from the atmosphere by pea as determined by the natural ^{15}N abundance method at Goodale in 1995 and at Kernen and Goodale in 1996.

Treatment		Rate (kg ai ha^{-1})	Application method[z]		% Ndfa		
					1995	1996	
Fall	Spring	Fall/Spring	Fall	Spring	Goodale	Kernen	Goodale
Ethalfluralin	Glyphosate[y]	0.84/0.27	PpSA	Burn off	43	44	45
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	38	39	49
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	18	48	40
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		30	48	47
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		42	45	50
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		29	43	40
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	41	45	53
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	30	38	46
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	30	44	52
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	27	45	45
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		34	49	48
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		35	45	57
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		22	46	60
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	36	39	48
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	27	39	52
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	21	36	56
None	Glyphosate	0.27		Burn off	46	37	46
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[w]	0.27 + 0.2		Burn off + PoE	41	49	47
None	Tillage				44	56	53
LSD (0.05)					18	14	15

[z] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[y] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent MCPA-Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[w] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

ethalfluralin at 1.4 kg ai ha^{-1} plus metribuzin surface applied in the fall, resulted in N_2-fixation lower than the commercial standard, ethalfluralin at 1.1 kg ai ha^{-1}, conventionally incorporated. These differences were minor and do not suggest that N_2-fixation was reduced where ethalfluralin was surface applied.

4.3 Economic Analysis

The prices of the individual herbicides and equipment rental costs can be used to calculate the cost of individual weed control treatments (Table 4.15). The lowest price grassy weed control options are presented in Table 4.16. The slight improvement in weed control derived from shallow or conventional incorporation is not economically justified. Triallate/trifluralin (10:4) can be successfully substituted for ethalfluralin for grassy weed control in pea and lentil. The cost of triallate/trifluralin (10:4) at 1.96 kg ai ha^{-1} is only slightly higher than ethalfluralin at the rate of 1.1 kg ai ha^{-1}. These products controlled high densities of wild oat and were suitable for control of green foxtail and volunteer wheat. While triallate/trifluralin (10:4) is not registered for volunteer wheat control, its control of wheat in these trials may be due to its placement in the same layer of soil as the wheat seeds. In addition, the glyphosate burn-off treatment may have contributed to volunteer wheat control.

Table 4.15 Herbicide prices and equipment rental costs[z].

Variable costs	$ ha^{-1}
Herbicides	
Ethalfluralin @ 0.84 kg ai ha^{-1}	28.80
1.1 kg ai ha^{-1}	38.68
1.4 kg ai ha^{-1}	48.19
Triallate/trifluralin (10:4) @ 1.96 kg ai ha^{-1}	41.32
Metribuzin @ 0.16 kg ai ha^{-1}	17.91
0.21 kg ai ha^{-1}	23.53
0.28 kg ai ha^{-1}	31.12
0.36 kg ai ha^{-1}	39.42
Glyphosate @ 0.27 kg ai ha^{-1}	16.67
Sethoxydim @ 0.42 kg ai ha^{-1}	40.58
MCPA-Na salt @ 0.4 kg ai ha^{-1}	4.37
0.8 kg ai ha^{-1}	7.87
Imazethapyr/imazamox (1:1) @ 0.02 kg ai ha^{-1}	42.73
Equipment rental	
Tandem disc	3.83
Harrows	0.91
PTO sprayer	3.14
Granular herbicide applicator	1.31

[z] Herbicide costs are from the 1995 Manufacturers retail price list (Saskatchewan Agriculture and Food, 1995b). Equipment rental costs are determined from the Farm Machinery Custom and Rental Rate Guide, 1995 (Saskatchewan Agriculture and Food, 1995a). The rental rate shown is the fixed rate plus repair costs and does not include any allowance for management costs and profit.

Table 4.16 Lowest cost treatments for acceptable grassy weed control in pea and lentil.

Treatment	Cost ha^{-1} ($)
Ethalfluralin @ 1.1 kg ai ha^{-1} shallowly incorporated + glyphosate pre-seeding burn-off	60.71
Triallate/trifluralin (10:4) @ 1.96 kg ai ha^{-1} surface applied + glyphosate pre-seeding burn-off	62.44
Triallate/trifluralin (10:4) @ 1.96 kg ai ha^{-1} shallowly incorporated + glyphosate pre-seeding burn-off	63.35
Ethalfluralin @ 1.4 kg ai ha^{-1} surface applied + glyphosate pre-seeding burn-off	69.31

The treatments listed in Table 4.16 resulted in acceptable control of most broadleaf weeds but kochia control was not acceptable when ethalfluralin was not conventionally incorporated. Weed species not included in the ethalfluralin weed spectrum are most economically controlled with post-emergent applications of MCPA-Na salt in pea and metribuzin in lentil. These options are more economical than fall-applied metribuzin treatments.

A cost comparison between the conventionally incorporated ethalfluralin and the reduced incorporation treatments resulting in similar grass and broadleaf weed control is shown (Table 4.17). Costs include the price of the herbicides and their application costs.

Table 4.17 Cost comparison for broad spectrum weed control options in pea and lentil.

Treatment	**Cost ha^{-1} ($)**
Ethalfluralin @ 1.1 kg ai ha^{-1} conventionally incorporated + MCPA-Na salt[z]	55.16
Ethalfluralin @ 1.1 kg ai ha^{-1} surface applied + glyphosate pre-seeding burn-off + MCPA-Na salt[z]	62.94
Ethalfluralin @ 1.1 kg ai ha^{-1} shallowly incorporated + glyphosate pre-seeding burn-off + MCPA-Na salt[z]	63.85
Ethalfluralin @ 1.4 kg ai ha^{-1} surface applied + glyphosate pre-seeding burn-off + MCPA-Na salt[z]	72.45

[z] For lentil, add $13.54 for the difference in cost between post-emergent MCPA-Na salt and metribuzin.

The lowest cost herbicide strategy for broad spectrum weed control in direct-seeding systems is ethalfluralin (at 1.1 kg ai ha^{-1} except for high densities of wild oat) surface applied or shallowly incorporated, followed by post-emergent applications of MCPA-Na salt in pea and metribuzin in lentil. Agronomically, the benefits of reduced incorporation include reduced erosion, improved soil moisture and reduced labour requirements, in addition to the cost advantage compared to conventional incorporation, the cheapest treatment.

5.0 DISCUSSION

5.1 Grassy Weed Control

Grassy weed control was acceptable with most reduced incorporation applications of the dinitroaniline herbicides. The level of control was enhanced as the rate of the herbicide increased, especially for high populations of grassy weeds.

Wild oat control was excellent with triallate/trifluralin (10:4) at 1.96 kg ai ha^{-1} when surface applied or shallowly incorporated. Ethalfluralin controlled dense populations of wild oat at a rate of 1.4 kg ai ha^{-1} when surface applied and at rates of 1.1 kg ai ha^{-1} and greater when shallowly incorporated. Ethalfluralin at 0.84 and 1.1 kg ai ha^{-1} did not control high populations of wild oat when surface applied. Shallow incorporation of ethalfluralin at 0.84 kg ai ha^{-1} enhanced control when the wild oat population was high. At lower populations, wild oat was controlled at all tested rates of ethalfluralin.

Green foxtail control was excellent with dinitroaniline herbicides in both years and both locations. Control did not vary with rate of ethalfluralin or method of incorporation. Volunteer wheat was controlled with dinitroaniline herbicides.

An analysis of the depth from which grassy weed escapes were emerging indicated that species escaping control emerged from varying depths from the soil surface to a maximum of 5 cm. No relationship was evident between the degree of dinitroaniline incorporation and the depth of emergence of dinitroaniline-susceptible weeds.

The experimental herbicide imazethapyr/imazamox (1:1) was applied in pea post-emergence for broad spectrum weed control following a glyphosate burn-off treatment. Visual assessment data indicate excellent control of green foxtail, volunteer wheat, wild oat, lamb's-quarters, stinkweed and volunteer canola.

Observation of the grassy weed dry weight biomass values in pea compared to lentil indicate that pea was more competitive than lentil. These findings are in accordance with those of Boerboom and Young (1995) with respect to the competitive ability of pea and lentil with broadleaf weeds. They reported that pea had a competitive advantage over lentil, likely due to its more vigourous growth and taller canopy.

5.2 Broadleaf Weed Control

Broadleaf weed control with reduced incorporation of ethalfluralin was variable. The population of broadleaf weeds normally controlled by ethalfluralin was low and inconsistent over sites and years, making the collection of reliable weed control data difficult.

Surface-applied and shallowly-incorporated ethalfluralin partially controlled wild buckwheat at Kernen in 1996, but not at Goodale. One possible explanation is that weed control was enhanced at Kernen because the surface applied seed more closely reflected the conditions prevalent in a low-disturbance direct seeding system, allowing greater herbicide-weed seed contact. The natural wild buckwheat population at Goodale escaped weed control because it may have germinated from below the herbicide-treated layer. As time in a low-disturbance direct seeding system increases, the increasing accumulation of weed seeds at the soil surface should eventually translate into improved weed control as the weed seeds will be in the same layer as the herbicide.

Kochia control was not satisfactory with a surface application or shallow incorporation of ethalfluralin at Kernen in 1996. Conventionally-incorporated ethalfluralin controlled kochia to an acceptable level. Lamb's-quarters was satisfactorily controlled with a combination of ethalfluralin and fall-applied or post-emergence metribuzin. The efficacy of ethalfluralin followed by post-emergence metribuzin appeared greater than fall-applied metribuzin and ethalfluralin as determined by visual control ratings.

Control of stinkweed, volunteer canola and wild mustard was better with post-emergent applications of metribuzin in lentil and MCPA-Na salt in pea, than with fall applied metribuzin in pea and lentil. In 1996, a high broadleaf weed biomass in the glyphosate burn-off treatment and ethalfluralin applied at 0.84 and 1.4 kg ai ha^{-1} in combination with fall-applied metribuzin was due to the high population of stinkweed and wild mustard that was not satisfactorily controlled by metribuzin. The efficacy of fall-applied metribuzin is not well established for use in conjunction with ethalfluralin in a direct seeding system for broad-spectrum weed control in pea and lentil.

5.3 Crop Tolerance

Emergence rate as determined at 11-13 DAS was enhanced by a shallow tillage operation in pea and lentil in both years at both locations. At 17-18 DAS, the tillage effect was still apparent in lentil, but not in pea. By 23-26 DAS, crop stand was similar among the tillage treatments in both crops. While pea and lentil emergence in zero tillage conditions may be slower than in conventionally tilled or shallowly tilled systems, differences in plant stand dissipated by 3-4 weeks after seeding. One factor contributing to the delay in emergence could be cooler soil temperature in the zero-till plots. As the degree of tillage increases, the soil exposure also increases, resulting in higher soil temperatures compared to untilled soil.

In 1996, ambient air temperature was higher during crop emergence than in 1995. Emergence rate was, as expected, much faster in 1996 than 1995. This is evident by comparing the number of plants emerged at 11-13 DAS in 1995 and 1996. The effect of the higher temperatures on emergence rate between years can be paralleled with the effect of tillage on emergence within one year.

These results suggest that tillage has more influence on emergence than the herbicide treatments tested as herbicides did not cause a delay in crop emergence. With the exception of MCPA-Na salt applied to the pea at Goodale in 1995, the days to 10% flower and days to desiccation were not affected by herbicide treatment (data not presented). Producers who apply MCPA-Na salt to their pea crops will have to consider that a slight delay in crop maturity may result. The increased injury suffered by the MCPA-Na salt-treated pea in the surface and shallowly incorporated ethalfluralin plots may have been due to reduced plant biomass at time of MCPA-Na salt application because of delayed emergence, thus appearing as increased injury when in fact it was simply not as advanced as the pea in the conventionally-tilled treatments.

Pea and lentil tolerance to the surface application of ethalfluralin and triallate/trifluralin (10:4), as determined by visual tolerance ratings, was excellent. Crop tolerance at 40-43 DAS after seeding, as assessed by visual ratings, did not exceed the limit for allowable injury in lentil in either year. Pea suffered injury from the post-emergent application of MCPA-Na salt as indicated by visual ratings, but yield with was not reduced when the MCPA-Na salt was applied within the recommended rate and stage of crop growth. In 1995, MCPA-Na salt was applied at 0.8 kg ai ha^{-1} and yield was reduced in some of these plots. Pea crop tolerance to fall-applied metribuzin is higher than to post-emergence MCPA-Na salt. Lentil yield was not affected by any of the dinitroaniline herbicide treatments in either year at either location.

5.4 N_2-fixation

Efficient N_2-fixation by pea and lentil depends heavily on a healthy shoot and root system and adequate crop nutrition as the process requires high energy inputs. An adverse effect on the root system of pea and lentil, such as might result from soil- and foliar-applied herbicides, may alter the N_2-fixing capacity of the plant. Metribuzin is taken up both by the shoots and the roots of pea and lentil and crop tolerance is based on enhanced herbicide metabolism by the plant (Devine *et al.*, 1993). MCPA-Na salt is also taken up by the shoots and roots of pea. A N_2-fixation analysis indicates that fall-applied ethalfluralin had no effect on N_2-fixation. Glyphosate burn-off and post-emergence applications of herbicides for broadleaf weed control in pea and lentil apparently did not affect N_2-fixation. The effect of metribuzin on N_2-fixation in pea and lentil remains inconclusive however, as there is indication that N_2-fixation may be reduced with fall applications of metribuzin applied in combination with ethalfluralin. Occasionally, conventionally incorporated treatments resulted in lower N_2-fixation values when compared to similar shallowly incorporated treatments. These results are in accordance with those of Matus *et al.* (1997) who reported increased N_2-fixation in zero-till pea and lentil compared to conventional tillage practices in these crops.

High values for N_2-fixation were expected as no N-fertilizer was added to the soil and the plants had to derive their nitrogen requirement from the existing soil nitrogen and the atmosphere once the soil reserves were depleted. Considerable variation in % Ndfa among the treatments was noted, but not to the extent reported by Stevenson *et al.* (1995) who reported variations in % Ndfa from 5 to 98% with the isotope dilution method and 41 to 100% with the natural ^{15}N abundance method at the micro-scale level (<1.5 m^2) in pea at maturity. This variability is due to a number of controls, including soil water and inorganic nitrogen content, as well as availability of other nutrients.

5.5 Economic Analysis

The cost of the herbicide and tillage treatments varied substantially, while weed control and crop tolerance among the majority of the treatments was not as variable. The major contributors to increases in costs of the individual treatments were the conventional incorporation tillage operations and the cost of fall-applied metribuzin.

With respect to weed control with ethalfluralin, rates greater than 1.1 kg ai ha^{-1} provided excellent grassy weed control when surface applied or shallowly incorporated, under low and high grass weed populations. The shallow incorporation offered little or no improvement in weed control compared to the surface application; thus the rotary harrow incorporation is, in most cases, an extra, unnecessary cost to the producer. Conventional incorporation of ethalfluralin improved control of kochia, but results are based on one site in one year only. The cost of conventional incorporation is \$7.66 ha^{-1} for a double incorporation and offers little in terms of additional weed control beyond that which can be provided by a surface application. Additional benefit to weed control and crop yield achieved from a conventional incorporation of ethalfluralin is small to insignificant.

Metribuzin is currently the only post-emergent herbicide registered in lentil for control of many *Brassicaceae* family weeds plus some additional weeds. Lentil producers do not have any other broadleaf weed control choice and, thus, price competition is non-existent. The performance of fall-applied metribuzin was unacceptable in both years and would not be an economically wise option for weed control taking into consideration its cost of \$31-\$39 ha^{-1}, depending upon the soil organic matter content. Post-emergent applications of metribuzin are more cost effective and offer enhanced weed control compared to fall application. The cost of post-emergent metribuzin is \$17.91 and \$23.51 ha^{-1} for 0.16 kg ai ha^{-1} and 0.21 kg ai ha^{-1} rates, respectively. When weeds are treated early, one application of metribuzin at 0.16 kg ai ha^{-1} may be the only post-emergent broadleaf weed control necessary.

Metribuzin is registered for post-emergent application in pea. However, other herbicide options are less costly for control of weeds not controlled by ethalfluralin and triallate/trifluralin (10:4). MCPA-Na salt, a commonly used, low-cost herbicide for post-emergent broadleaf weed control in pea, costs \$4.37 ha^{-1} when applied at the highest recommended rate. MCPA-Na salt may cause a delay in maturity as tolerance in pea is based on enhanced metabolism of the herbicide (Devine, 1995). Water volumes of 200 litres ha^{-1} are recommended and good growing conditions at the time of application improve crop tolerance. MCPA-Na salt, in combination with a spring burn-off treatment with glyphosate, is more economical than metribuzin alone and should be used as a cost effective means of broadleaf weed control in pea to supplement fall-applied ethalfluralin or triallate/trifluralin (10:4). The most economical option for broad spectrum weed control for pea and lentil producers is ethalfluralin at 1.1 kg ai ha^{-1} surface applied followed by a pre-seeding burn-off with glyphosate at 0.27 kg ai ha^{-1} and then post-emergent metribuzin at 0.16 kg ai ha^{-1} in lentil and MCPA-Na salt applied at 0.46 kg ai ha^{-1} in pea.

5.6 Future Research Needs

Future research in direct-seeded pea and lentil crop protection may include a number of areas. The impact of a single herbicide, in a weed free environment, on N_2-fixation in pea and lentil should be studied. Many factors which may have influenced N_2-fixation were present in this research project and may have masked the herbicide effect on N_2-fixation.

Other areas for research focus on weed control in direct-seeded pea and lentil. An evaluation of weed control, with a surface application or shallow incorporation of the dinitroaniline herbicides, in a cropping system that has been in a low-disturbance, direct-seeding system for five years or greater would be beneficial. This time period will allow the weed population, weed seed distribution and soil characteristics to become more representative of a low-disturbance, direct seeding management regime. A third area of research would include gathering more information on the performance of surface-applied and shallowly-incorporated ethalfluralin on hard-to-control weeds, such as kochia. Also, data collection on weeds that would be used for label extensions of ethalfluralin in direct-seeded pea and lentil could be included in future research projects.

6.0 SUMMARY AND CONCLUSIONS

Excellent crop tolerance was observed to all rates of ethalfluralin and the 1.96 kg ai ha^{-1} rate of triallate/trifluralin (10:4) either surface applied or shallowly incorporated. None of the herbicides tested affected crop emergence rate. Tillage treatment affected the rate of pea and lentil emergence with faster emergence occurring in plots that were tilled. Lentil and pea yield was not affected by any of the dinitroaniline herbicide/tillage treatments.

Pea tolerance to metribuzin was excellent. Lentil tolerance to metribuzin applied in the spring as a post-emergent treatment was less than the tolerance observed to metribuzin applied in the fall. This difference in lentil tolerance is likely a reflection of the differing herbicide availabilities between the two types of application. Pea tolerance to MCPA-Na salt was not acceptable when the herbicide was applied to the crop at greater than recommended rates or when environmental conditions were not conducive to rapid metabolism of the herbicide. Cool conditions at the time of MCPA-Na salt application to pea may reduce herbicide metabolism and contribute to pea injury if pea growth is affected.

N_2-fixation apparently was not inhibited by a glyphosate burn-off treatment. Reductions in N_2-fixation are likely caused by herbicide treatments which adversely affect the crop shoots and roots. Further investigation into the effect of metribuzin, MCPA-Na salt, and the dinitroanilines on the N_2-fixing ability of pea and lentil is warranted.

Excellent grassy weed control was achieved with dinitroaniline plus glyphosate herbicide treatments. Green foxtail was more easily controlled by the dinitroaniline herbicide treatments than was wild oat. Heavy wild oat infestations require either a higher rate (greater than 0.84 kg ai ha^{-1}) of ethalfluralin or a slight incorporation of the herbicide, if the rate is not increased above 0.84 kg ai ha^{-1}. Low populations of volunteer wheat were adequately controlled by all rates of ethalfluralin and all levels of incorporation.

Reduced incorporation of ethalfluralin resulted in acceptable control of lamb's-quarters. Wild buckwheat was controlled when the seeds were in the surface layer of soil, but seeds germinating below the treated layer escaped control. Kochia control was not acceptable when ethalfluralin was surface applied or shallowly incorporated.

Metribuzin applied post-emergence was much more effective and economical than fall-applied metribuzin for *Brassicaceae* family weed control in lentil. MCPA-Na salt, applied post-emergence in pea, provided greater weed control at a lower cost than fall-applied metribuzin, but some crop injury was noted. This injury may translate into a slight delay in maturity under dry or cool growing conditions.

Shallow incorporation of the dinitroaniline herbicides will increase the herbicide:soil contact and may reduce yield losses from weeds. Shallow incorporation with a rotary harrow increases weed control when weed pressure is heavier. This incorporation should be left to the discretion of the producer.

The results from this research should be available to producers when they consider their options regarding broad-spectrum weed control in low-disturbance, direct-seeded pea and lentil production systems. The use of ethalfluralin in a reduced incorporation system is not registered yet, however.

The advantages of using dinitroaniline herbicides for weed control in direct-seeded pea and lentil are numerous, including: reduced costs, less potential for soil erosion and increased time savings. Weed control strategies involving fall-applied ethalfluralin or triallate/trifluralin (10:4), glyphosate applied as a pre-seeding burn-off followed by post-emergent herbicides such as metribuzin in lentil and MCPA-Na salt in pea, are agronomically favorable. These weed control options offer excellent weed control without affecting crop seed yield and contribute to the appeal of surface or shallowly incorporated dinitroaniline herbicides. The decision to use the dinitroaniline herbicides as part of a weed control strategy in direct-seeded pea and lentil positively addresses economic, management, and environmental concerns.

7.0 REFERENCES CITED

Ahrens, W.H. and G.J. Endres. 1996. Trifluralin and ethalfluralin in conservation-tillage soybeans (*Glycine max*). Can. J. Plant Sci. 76:891-897.

Arshad, M.A., K.S. Gill and G.R. Coy. 1994. Wheat yield and weed population as influenced by three tillage systems on a clay soil in temperate continental climate. Soil & Tillage Res. 28:227-238.

Arshad, M.A., K.S. Gill and G.R. Coy. 1995. Barley, canola, and weed growth with decreasing tillage in a cold, semiarid climate. Agron. J. 87:49-55.

Baker, R.J. 1995. CR SC 813 - Statistical methods in life sciences, lecture notes. Department of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon SK.

Banks, P.A. and E.L. Robinson. 1982. The influence of straw mulch on the soil reception and persistence of metribuzin. Weed Sci. 30:164-168.

Bergensen, F.J. 1978. N2 Fixation: Physiology of Legume Symbiosis Process. In: Interactions between non-pathogenic soil microorganisms and plants. Edited by Y.R. Dommergues and S.V. Krupa. Amsterdam; New York: Elsevier Scientific Pub. Co.; New York: Elsevier North-Holland. Pp:305-333.

Blackshaw, R. E., F.O. Larney, C.W. Lindwall and G.C. Kozub. 1994. Crop rotation and tillage effects on weed populations on the semi-arid Canadian Prairies. Weed Tech. 8:231-237.

Boerboom, C.M. and F.L. Young. 1995. Effect of postplant tillage and crop density on broadleaf weed control in dry pea (*Pisum sativum*) and lentil (*Lens culinaris*). Weed Tech. 9:99-106.

Bremer, E. and C van Kessel. 1990. Appraisal of the nitrogen-15 natural abundance method for quantifying dinitrogen fixation. Soil Sci. Soc. Am. J. 54:404-411.

Cardina, J., N.L. Hartwig and F.L. Lukezic. 1986. Herbicidal effects on crown vetch rhizobia and nodule activity. Weed Sci. 34:338-343.

Clark, S.A. and H.K. Mahanty. 1991. Influence of herbicides on growth and nodulation of white clover, *Trifolium repens*. Soil Biol. Biochem. 23(8):725-730.

Derksen, D.A. and A.G. Thomas. 1996. Dandelion control in cereal and oilseed crops. Expert Committee on Weeds, Proceedings of the 1996 National Meeting. Pp:63-69

Derksen, D.A., A.G. Thomas, G.P. Lafond, H.A. Loeppky and C.J. Swanton. 1995. Impact of post-emergence herbicides on weed community diversity within conservation-tillage systems. Weed Res. 35:311-320.

Derksen, D.A., G.P. Lafond, A.G. Thomas, H.A. Loeppky and C.J. Swanton. 1993. Impact of agronomic practices on weed communities: tillage systems. Weed Sci. 41:409-417.

Devine, M.D., S.O. Duke, and C. Fedtke. 1993. Physiology of herbicide action. PTR Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Devine, M.D. 1995. Crop Science 818 - Physiology and biochemistry of herbicide action, lecture notes. Department of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon SK.

Dick, W. A. and T.C. Daniel. 1987. Soil chemical and biological properties as affected by conservation tillage: Environmental implications. pp:125-147 In: T.J. Logan, J.M. Davidson, J.L. Baker, and M.R. Overcash, eds. Effectws of conservation tillage on groundwater quality. Lewis Publishers, Inc., Chelsea, MI.

DowElanco Canada Inc. 1996. Edge Granular Label. Suite 201 - 1144 29 Ave. N.E., Calgary AB T2E 7P1.

Eberbach, P.L. and L.A. Douglas. 1989. Herbicide effects on the growth and nodulation potential of *Rhizobium trifolii* with *Trifolium subterraneum* L. Plant and Soil 119:15-23.

Endres, G.J. and W.H. Ahrens. 1995. Fall-applied trifluralin granules in conservation-till spring wheat (*Triticum aestivum*). Weed Tech. 9:703-709.

Fawcett, R.S., B.R. Christensen and D.P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: A review and analysis. J. Soil and Water Cons. 49:126-135.

Friesen, G.H. and D.A. Wall. 1986. Tolerance of lentil (*Lens culinaris* Medik.) to herbicides. Can. J. Plant Sci. 66:131-139.

Gebhardt, M.R., T.C. Daniel, E.E. Schweizer, and R.R. Allmaras. 1985. Conservation tillage. Science 230:625-630.

Germida, J.J., A.E. Slinkard and L.M. Nelson. 1988. Growth and nitrogen fixation of field pea and lentil as influenced by herbicides: a three year field study. Proceedings of the Soils and Crops Workshop. University of Saskatchewan, Saskatoon SK. 1:248-257.

Grover, R., A.E. Smith, S.R. Shewchuk, A.J. Cessna and J.H. Hunter. 1988. Fate of trifluralin and triallate applied as a mixture to a wheat field. J. Environ. Qual. 17:543-550.

Kirkland, K.J. 1994. Efficacy of fall incorporated and non-incorporated granular triallate on wild oat (*Avena fatua*) and wheat (*Triticum aestivum*). Weed Tech. 8:607-611.

Kumar, K. and J.S. Kolar. 1989. Effect of chemical weed control and *Rhizobium* inoculation on the yield of lentil. J. Res. Punjab Agric Univ. 26:19-24.

Lafond, G.P., R.P. Zentner, R. Geremia and D.A. Derksen. 1993. The effects of tillage systems on the economic performance of spring wheat, winter wheat, flax and field pea production in east-central Saskatchewan. Can. J. Plant Sci. 73:47-54.

Lal, R. and S. Lal, eds. 1988. Effects of pesticides on *Rhizobium*-legume symbiosis. In: Pesticides and the nitrogen cycle. 3:48-67. CRC Press, Inc. Boca Raton FL.

Malik, N. and L. Townley-Smith. 1990. Performance of imazethapyr on pulse crops. Weed Tech. 4:791-798.

Mårtensson, A.M. 1992. Effects of agrochemicals and heavy metals on fast growing rhizobia and their symbiosis with small-seeded legumes. Soil Biol. Biochem. 24:435-445.

Matus, A., D.A. Derksen, F.L. Walley, H.A. Loeppky, and C. van Kessel. 1997. The influence of tillage and crop rotation on nitrogen fixation in lentil and pea. Can. J. Plant Sci. 77:197-200.

Peoples, M.B., A.W. Faizah, B. Rerkasem and D.F. Herridge. (eds). 1989. Methods for evaluating nitrogen fixation by nodulated legumes in the field. ACIAR Monograph No. 11, ACIAR, Canberra, Australia.

Reichardt, K.G., G. Hardarson, F. Zapata, C. Kirda and S.K.A. Danso. 1987. Site variability effect on field measurement of symbiotic nitrogen fixation using the ^{15}N isotope dilution method. Soil Biochem. 19:405-409.

Rennie, R.J. 1984. Comparison of N balance and ^{15}N Isotope dilution to quantify N_2 fixation in field-grown legumes. Agron. J. 76:785-790.

Rennie, R.J. and S. Dubetz. 1986. Nitrogen-15-determined nitrogen fixation in field-grown chickpea, lentil, fababean, and field pea. Agron. J. 78:654-660.

Saskatchewan Agriculture and Food. 1995a. Farm machinery custom and rental rate guide 1995. Saskatchewan Agriculture and Food, Regina SK.

Saskatchewan Agriculture and Food. 1995b. Manufacturers retail price list 1995. Saskatchewan Agriculture and Food, Regina SK.

Saskatchewan Agriculture and Food. 1995c. Revised guidelines for safe rates of fertilizer applied with the seed. Saskatchewan Agriculture and Food, Regina SK.

Saskatchewan Agriculture and Food. 1996. Agricultural statistics fact sheet. Saskatchewan Agriculture and Food, Regina SK.

Saskatchewan Agriculture and Food. 1997a. Crop protection guide. Saskatchewan Agriculture and Food, Regina SK.

Saskatchewan Agriculture and Food. 1997b. Specialty crop report. Saskatchewan Agriculture and Food, Regina SK.

Shearer, G. and D.H. Kohl. 1986. N_2-fixation in field settings: Estimations based on natural ^{15}N abundance. Aust. J. Plant Physiol. 13:699-756.

Shearer, G., D.H. Kohl and J.E. Harper. 1980. Distribution of ^{15}N among plant parts of nodulating and nonnodulating isolines of soybeans. Plant Physiol. 66:57-60.

Slinkard, A.E. and F.A. Holm. 1989. Lentil production in western Canada. Farm Facts. Saskatchewan Agriculture and Food, Regina SK.

Slinkard, A.E., F.A. Holm, R. McVicar, D. Kaminski, L. Kaminski, and J. Soroka. 1995. Dry pea production in Saskatchewan. Saskatchewan Agriculture and Food, Regina SK.

Smith, S.C., D.F. Bezdicek, R.F. Turco and H.H. Cheng. 1987. Seasonal N_2 fixation by cool-season pulses based on several ^{15}N methods. Plant Soil 97:3-13.

Sprout, S.L., L.M. Nelson and J.J. Germida. 1988. A growth chamber study on the effects of metribuzin on the *Rhizobium*-lentil symbiosis. Proceedings of the Soils and Crops Workshop. University of Saskatchewan, Saskatoon SK. 1:262-265.

Statistical Analysis Systems Institute. 1987. SAS User's Guide. Version 6. SAS Institute Inc., Cary NC.

Stevenson, F.C. 1996. A landscape-scale and small-plot assessment of the nitrogen and non-nitrogen rotation benefits of pea. Ph.D. Thesis. Department of Soil Science, University of Saskatchewan, Saskatoon SK.

Stevenson, F.C., J.D. Knight and C. van Kessel. 1995. Dinitrogen fixation in pea: controls at the landscape- and micro-scale. Soil Sci. Soc. Am. J. 59:1603-1611.

Swanton, C.J., D.R. Clements and D.A. Derksen. 1993. Weed succession under conservation tillage: a hierarchical framework for research and management. Weed Tech. 7:286-297.

Thomas, G.W. 1985. Managing minimum tillage fields, fertility, and soil type. In: Weed Control in Limited Tillage Systems. Edited by A.F. Wiese, Champaign IL: Weed Science Society of America. pp:211-226.

Unger, P.W. 1990. Conservation tillage systems. Adv. Soil Sci. 13:27-68.

Vaughn, K.C. and L.P. Lehnen. 1991. Mitotic disrupter herbicides. Weed Sci. 39:450-457.

Wall, D. A. 1994. Response of flax and lentil to seeding rates, depths and spring application of dinitroaniline herbicides. Can. J. Plant Sci. 74:875-882.

Wall, D.A., G.H. Friesen and T.K. Bhati. 1991. Wild mustard interference in traditional and semi-leafless field peas. Can. J. Plant Sci. 71:473-480.

Weber, J.B. 1990. Behavior of dinitroaniline herbicides in soils. Weed Tech. 4:394-406.

Weber, J.B. and S.W. Lowder. 1985 Soil factors affecting herbicide behavior in reduced-tillage systems. In: Weed Control in Limited Tillage Systems. Edited by A.F. Wiese, Champaign IL: Weed Science Society of America. pp:227-241.

Weston, L.A. 1990. Cover crop and herbicide influence on row crop seedling establishment in no-tillage culture. Weed Sci. 38:166-171.

APPENDIX 1

Table A1.1 Treatment list for lentil at Kernen, 1995.

Treatment	Concentration and formulation	Rate (kg ai ha^{-1})	Application code	Fall (F) or Spring (S)
Ethalfluralin +	5 G	0.84	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.4	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSA	F
Metribuzin	75WG	0.36	PpSA	F
Ethalfluralin +	5 G	1.1	PpSA	F
Metribuzin	75 WG	0.36	PpSA	F
Ethalfluralin +	5 G	1.4	PpSA	F
Metribuzin	75 WG	0.36	PpSA	F
Triallate/trifluralin	5 G	1.96	PpSA	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.4	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Ethalfluralin +	5 G	1.1	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Ethalfluralin +	5 G	1.4	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpI	F
Metribuzin +	75 WG	0.36	PpI	F
Tillage			Pre	S
Ethalfluralin +	5 G	1.1	PpI	F
Tillage +	75 WG	0.20	Pre	S
Metribuzin			PoE	S
Glyphosate	356 SN	0.27	Pre	S
Glyphosate +	356 SN	0.27	Pre	S
Sethoxydim	202 EC	0.18	PoE	S
Merge		0.75		
Untreated +Tillage			Pre	S

Table A1.2 Treatment list for lentil at Goodale 1995 and 1996, and Kernen 1996.

Treatment	**Concentration and formulation**	**Rate (kg ai ha^{-1})**	**Application code**	**Fall (F) or Spring (S)**
Ethalfluralin +	5 G	0.84	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.1	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.4	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	0.84	PpSA	F
Metribuzin	75 WG	0.28[z]	PpSA	F
Ethalfluralin +	5 G	1.1	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Ethalfluralin +	5 G	1.4	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
+ Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.1	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.4	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.1	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.4	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
+ Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.1	PpI	F
Metribuzin +	75 WG	0.28	PpI	F
Tillage +			Pre	S
Metribuzin	75 WG	0.16	PoE	S
Ethalfluralin +	5 G	1.1	PpI	F
Tillage +			Pre	S
Metribuzin	75 WG	0.16	PoE	S
Glyphosate	356 SN	0.27	Pre	S
Glyphosate +	356 SN	0.27	Pre	S
Metribuzin +	75 WG	0.21	PoE	S
Sethoxydim +	202 EC	0.18	PoE	S
Merge		0.75		
Untreated +				
Tillage			Pre	S

[z] Fall metribuzin at Kernen applied at 0.36 kg ai ha^{-1}.

Table A1.3 Treatment list for pea at Goodale, 1995.

Treatment	Concentration and formulation	Rate (kg ai ha^{-1})	Application code	Fall (F) or Spring (S)
Ethalfluralin +	5 G	0.84	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	1.1	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	1.4	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	0.84	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Ethalfluralin +	5 G	1.1	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Ethalfluralin +	5 G	1.4	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
+ MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	1.1	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	1.4	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.1	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.4	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
+ MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +	5 G	1.1	PpI	F
Metribuzin +	75 WG	0.28	PpI	F
Tillage +			Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Ethalfluralin +_	5 G	1.1	PpI	F
Tillage +			Pre	S
MCPA-Na salt	300 SN	0.8	PoE	S
Glyphosate	356 SN	0.27	Pre	S
Glyphosate +	356 SN	0.27	Pre	S
Imazamox/	70 WG	0.02	PoE	S
imazethapyr (1:1) +			PoE	S
Agral 90		0.25		
Untreated +				
Tillage			Pre	S

Table A1.4 Treatment list for pea at Kernen, 1995.

Treatment	Concentration and formulation	Rate (kg ai ha^{-1})	Application code	Fall (F) or Spring (S)
Ethalfluralin +	5 G	0.84	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.4	PpSA	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSA	F
Metribuzin	75 WG	0.36	PpSA	F
Ethalfluralin +	5 G	1.1	PpSA	F
Metribuzin	75 WG	0.36	PpSA	F
Ethalfluralin +	5 G	1.4	PpSA	F
Metribuzin	75 WG	0.36	PpSA	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.4	PpSI	F
Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	0.84	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Ethalfluralin +	5 G	1.1	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Ethalfluralin +	5 G	1.4	PpSI	F
Metribuzin	75 WG	0.36	PpSI	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate	356 SN	0.27	Pre	S
Ethalfluralin +	5 G	1.1	PpI	F
Metribuzin +	75 WG	0.28	PpI	F
Tillage			Pre	S
Ethalfluralin +	5 G	1.1	PpI	F
Tillage +			Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Glyphosate	356 SN	0.27	Pre	S
Glyphosate +	356 SN	0.27	Pre	S
Sethoxydim +	184 EC	0.20	PoE	S
Merge		0.75		
Untreated +				
Tillage			Pre	S

Table A1.5 Treatment list for pea at Kernen and Goodale, 1996.

Treatment	Concentration and formulation	Rate (kg ai ha^{-1})	Application code	Fall (F) or Spring (S)
Ethalfluralin +	5 G	0.84	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.1	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.4	PpSA	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	0.84	PpSA	F
Metribuzin	75 WG	0.28[z]	PpSA	F
Ethalfluralin +	5 G	1.1	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Ethalfluralin +	5 G	1.4	PpSA	F
Metribuzin	75 WG	0.28	PpSA	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.1	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.4	PpSI	F
Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	0.84	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.1	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Ethalfluralin +	5 G	1.4	PpSI	F
Metribuzin	75 WG	0.28	PpSI	F
Triallate/trifluralin	5 G	1.96	PpSI	F
(10:4) + Glyphosate +	356 SN	0.27	Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.1	PpI	F
Metribuzin +	75 WG	0.28	PpI	F
Tillage +			Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Ethalfluralin +	5 G	1.1	PpI	F
Tillage +			Pre	S
MCPA-Na salt	300 SN	0.46	PoE	S
Glyphosate	356 SN	0.27	Pre	S
Glyphosate +	356 SN	0.27	Pre	S
Imazamox/	70 WG	0.02	PoE	S
imazethapyr (1:1) +			PoE	S
Agral 90		0.25		
Untreated +				
Tillage			Pre	S

[z] Fall metribuzin applied at Kernen at 0.36 kg ai ha^{-1}.

Table A1.6 List of product and chemical names used in the experiments.

Product Name	Chemical Name
Edge	Ethalfluralin
Fortress	Triallate/trifluralin (10:4)
MCPA-Na salt	MCPA-Na salt
Odyssey	Imazamox/imazethapyr (1:1)
Poast	Sethoxydim
Roundup	Glyphosate
Sencor	Metribuzin
Surfactants	
Agral 90	
Merge	

APPENDIX 2

Table A2.1 Wild oat biomass 60-75 DAS[z] following various herbicide treatments in lentil at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Wild oat biomass (dry weight g m^{-2}) Kernen 1995	Kernen 1996	Goodale 1995	Goodale 1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	0	0	39	0
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	1	0	26	5
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	1	0	6	3
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		0	0	10	0
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		1	0	11	1
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		0	20	5	0
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	0	0	1	0
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	2	0	11	0
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	0	0	2	0
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	0	6	2
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		1	17	9	20
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		0	1	3	2
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		0	2	4	0
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	0	2	3	0
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.46	PpI	PoE	0	5	1	1
Ethalfluralin	Tillage + Metribuzin	1.1/0.46	PpI	PoE	0	1	1	0
None	Glyphosate	0.27		Burn off	18	0	62	0
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	16	0	2	0
None	Tillage				43	31	87	5
LSD (0.05)					11	19	31	13
Contrasts:								
Ethalfluralin rates					NS	NS	NS	NS
Ethalfluralin PpSA vs PpSI					NS	NS	NS	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin					NS	NS	NS	NS
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS	NS

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.

[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Table A2.2 Percentage control[z] of broadleaf weeds 40-67 DAS[y] following various herbicide treatments in lentil at Goodale in 1995 and Kernen in 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[x] Fall	/ Spring	Control (%) Lamb's-quarters Goodale 1995	Stink-weed Goodale 1995	Kochia Kernen 1996
Ethalfluralin	Glyphosate[w]	0.84/0.27	PpSA	Burn off	71	94	76
Ethalfluralin	Glyphosate	1.1/.27	PpSA	Burn off	91	91	70
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	94	94	78
Ethalfluralin + Metribuzin	None	0.84 + 0.36[v]	PpSA		68	81	50
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		75	76	59
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		81	69	55
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	78	91	60
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	90	88	65
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	89	88	60
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	80	93	54
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		61	50	30
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		75	63	43
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		79	69	28
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	84	84	73
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	98	99	90
Ethalfluralin	Tillage + Metribuzin	1.1/0.16	PpI	PoE	95	75	90
None	Glyphosate	0.27		Burn off	25	51	15
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.20		Burn off + PoE	89	98	10
None	Tillage				0	0	0

[z] Assessed on a scale of 0-100% with 0 = no control and 100= complete control.
[y] Days after seeding.
[x] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.
[w] Spring glyphosate treatments (with the exception of the last two treatments) were followed by post-emergent metribuzin at 0.16 kg ai ha^{-1} in 1996 and at Goodale in 1995.
[v] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Table A2.3 Wild oat biomass 60-76 DAS[z] following various herbicide treatments in pea at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Wild oat biomass (dry weight g m^{-2}) Kernen 1995	Kernen 1996	Goodale 1995	Goodale 1996
Ethalfluralin	Glyphosate[x]	0.84/0.27	PpSA	Burn off	0	4.4	45	0.5
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	0	0	10	0.7
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	0.1	0	13	1.8
Ethalfluralin + Metribuzin	None	0.84 + 0.36[w]	PpSA		0.3	0	7	1.6
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		0	0	2	1.0
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		0	8.6	0	0.0
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	0	0	15	0
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	0.6	0.4	20	0.2
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	0	3.2	2	0
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	0	0	2	0.4
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		0.0	0	7	0.5
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		0.9	5.4	1	0.4
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		0	0	0	0
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	0	0.3	22	0
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	0	4.0	0	0
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	0	0	0	1.0
None	Glyphosate	0.27		Burn off	7.3	2.3	59	0.3
None	Glyphosate + Imazamox/ Imazethapyr (1:1)[v]	0.27 + 0.2		Burn off + PoE	4.6	0	11	0
None	Tillage				20.4	8.2	71	6.2
LSD (0.05)					4.9	NS	41	NS
Contrasts:					-	-	NS	-
Ethalfluralin rates					-	-	NS	-
Ethalfluralin PpSA vs PpSI					-	-	NS	-
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin					-	-	NS	-
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					-	-	NS	-
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					-	-	NS	-

[z] Days after seeding.
[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.
[x] Spring glyphosate treatments were followed by PoE MCPA- Na salt at 0.46 kg ai ha^{-1} in 1996 and 0.8 kg ai ha^{-1} at Goodale in 1995.
[w] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.
[v] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

APPENDIX 3

Table A3.1 Treatment means for lentil plant stand 11-13 DAS[z] at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate ($kg\ ai\ ha^{-1}$) Fall / Spring	Application method[y] Fall	/ Spring	Lentil stand ($plants\ m^{-2}$) 1995	1996	Mean
Ethalfluralin	Glyphosate	0.84/0.27	PpSA	Burn off	1	88	45
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	2	87	44
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	0	90	45
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		0	109	54
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		2	89	46
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		0	91	46
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	1	89	45
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	11	116	63
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	7	110	58
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	8	124	66
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		7	122	64
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		8	125	66
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		4	114	59
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	7	116	61
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	10	123	67
Ethalfluralin	Tillage + Metribuzin	1.1/0.21	PpI	PoE	7	131	69
None	Glyphosate	0.27		Burn off	0	110	55
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	1	96	49
None	Tillage				5	124	64
LSD (0.05)					7	24	15
Contrasts:							
Ethalfluralin rates					NS	NS	NS
Ethalfluralin PpSA vs ethalfluralin PpSI					**	**	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin + PpSA and PpSI + metribuzin					NS	NS	NS
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 $kg\ ha^{-1}$)					NS	NS	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 $kg\ ha^{-1}$)					NS	*	NS

*, **, NS Significant at the 0.05, 0.01 level of probability and not significant, respectively.

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Table A3.2 Treatment means for lentil plant stand 17 DAS[z] at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall / Spring	Application method[y] Fall	/ Spring	Lentil stand (plants m^{-2}) 1995	1996	Mean
Ethalfluralin	Glyphosate	0.84/0.27	PpSA	Burn off	82	140	111
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	74	134	104
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	63	143	103
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		77	151	114
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		76	154	115
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		63	148	106
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	77	147	112
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	105	151	128
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	93	152	123
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	92	157	124
Ethalfluralin + Metribuzin	None	0.84 + 0.36	PpSI		91	156	124
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		92	158	125
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		89	153	121
Triallate/trifluralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	91	148	119
Ethalfluralin + Metribuzin	Tillage + Metribuzin	1.1+0.36/ 0.16	PpI	PoE	119	151	135
Ethalfluralin	Tillage + Metribuzin	1.1/0.21	PpI	PoE	92	150	121
None	Glyphosate	0.27		Burn off	89	148	118
None	Glyphosate + Metribuzin + Sethoxydim	0.27 + 0.16 + 0.2		Burn off + PoE	87	142	115
None	Tillage				101	149	125
LSD (0.05)					20	14	21
Contrasts:							
Ethalfluralin rates					NS	NS	NS
Ethalfluralin PpSA vs PpSI					**	*	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin + PpSA and PpSI + metribuzin					NS	NS	NS
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS

*, **, NS Significant at the 0.05, 0.01 level of probability and not significant, respectively

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

Table A3.3 Treatment means for pea plant stand 11-13 DAS[z] at Kernen and Goodale, 1995 and 1996.

Treatment Fall	/ Spring	Rate (kg ai ha^{-1}) Fall/ Spring	Application method[y] Fall	/ Spring	Pea stand ($plants\ m^{-2}$) 1995	1996	Mean
Ethalfluralin	Glyphosate	0.84/0.27	PpSA	Burn off	1.1	10	6
Ethalfluralin	Glyphosate	1.1/0.27	PpSA	Burn off	0.4	9	5
Ethalfluralin	Glyphosate	1.4/0.27	PpSA	Burn off	0.5	12	6
Ethalfluralin + Metribuzin	None	0.84 + 0.36[x]	PpSA		0.4	13	7
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSA		0.5	9	5
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSA		1.1	12	7
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSA	Burn off	1.3	12	7
Ethalfluralin	Glyphosate	0.84/0.27	PpSI	Burn off	4.1	15	7
Ethalfluralin	Glyphosate	1.1/0.27	PpSI	Burn off	1.1	16	9
Ethalfluralin	Glyphosate	1.4/0.27	PpSI	Burn off	2.1	22	12
Ethalfluralin + Metribuzin	None	0.84 + 0 .36	PpSI		0.9	21	11
Ethalfluralin + Metribuzin	None	1.1 + 0.36	PpSI		2.9	15	9
Ethalfluralin + Metribuzin	None	1.4 + 0.36	PpSI		1 .3	23	12
Triallate/triflu-ralin (10:4)	Glyphosate	1.96/0.27	PpSI	Burn off	2.0	21	12
Ethalfluralin + Metribuzin	Tillage + MCPA-Na salt	1.1+0.36/ 0.46	PpI	PoE	9.3	36	23
Ethalfluralin	Tillage + MCPA-Na salt	1.1/0.46	PpI	PoE	10.6	33	22
None	Glyphosate	0.27		Burn off	0.4	17	8
None	Glyphosate + Imazamox/ Imazethapyr[w]	0.27 + 0.2		Burn off + PoE	1.1	11	6
None	Tillage				3.4	30	17
LSD (0.05)					2.8	9.0	9.6
Contrasts:							
Ethalfluralin rates					NS	NS	NS
Ethalfluralin PpSA vs ethalfluralin PpSI					NS	**	NS
Ethalfluralin PpSA and PpSI + glyphosate vs ethalfluralin PpSA and PpSI + metribuzin					NS	NS	NS
Triallate/trifluralin PpSA and PpSI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					NS	NS	NS
Ethalfluralin PpI vs ethalfluralin PpSA and PpSI (1.1 kg ha^{-1})					**	**	NS

**, NS Significant at the 0.01 level of probability and not significant, respectively.

[z] Days after seeding.

[y] PpSA = preplant surface application, PpSI = preplant shallow incorporation with rotary harrows, PpI = preplant conventional incorporation.

[x] Fall metribuzin applied at 0.28 kg ai ha^{-1} at Goodale.

[w] Sethoxydim applied instead of imazamoz/imazethapyr (1:1) at Kernen in 1995.

Table A3.4 Combined ANOVA for lentil plant stand 11-13 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	820 457**
Locations	1	318
Year*location	1	7
Block(Year*location)	12	787**
Treatments	18	1330
Years*treatment	18	655*
Locations*treatment	18	309
Years*locations*treatment	18	255
Error	216	187

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

Table A3.5 Combined ANOVA for lentil plant stand 17-18 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	292 454**
Locations	1	27 837
Year*location	1	1 758
Block(Year*location)	12	578
Treatments	18	1 133
Year*treatment	18	634*
Location*Treatment	18	374
Year*location*treatment	18	175
Error	216	373

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

Table A3.6 Combined ANOVA for lentil plant stand 23-26 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	44 281
Locations	1	1 701
Year*location	1	11 838**
Block(Year*location)	12	142
Treatments	18	227
Year*treatment	18	318
Location*treatment	18	297
Year*location*treatment	18	227
Error	216	234

** Significant at 0.01 level of probability.

Table A3.7 Combined ANOVA for pea plant stand 11-13 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	18 000
Locations	1	6 000
Year*location	1	6 000**
Block(Year*location)	12	150*
Treatments	18	450*
Year*treatment	18	150*
Locations*treatment	18	50
Year*location*treatment	18	31
Error	216	32

*, ** Significant at the 0.05 and 0.01 level of probability, respectively.

Table A3.8 Combined ANOVA for pea plant stand 17-18 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	25 400*
Locations	1	3 150
Year*location	1	1 570*
Block(Year*location)	12	223
Treatments	18	396
Year*treatment	18	83
Location*treatment	18	128
Year*location*treatment	18	109
Error	216	139

* Significant at the 0.05 level of probability.

Table A3.9 Combined ANOVA for pea plant stand 23-26 DAS at Kernen and Goodale, 1995 and 1996.

Source of variation	df	MS
Years	1	258
Locations	1	2 366
Year*location	1	4 245
Block(Year*location)	12	51
Treatments	18	71
Year*treatment	18	136
Location*treatment	18	106
Year*location*treatment	18	166
Error	216	141

Not significant.