Chemical Weed Control

Options in Fibre Flax

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To my ancestors,

Auf ewig bleiben wir
verloren,
Wird nicht des Reiches
Schöpfers Geist
In jedem von uns neu
geboren,
In jedem, der ein Deutscher
heißt

Deutsche Gedenkhalle, 1923

Abstract

Experiments assessing pre-plant incorporated (PPI) and pre-emerge (PRE) herbicide treatments on fibre flax cultivar Ariane, and post-emerge (POST) herbicide tank-mix treatments on fibre flax cultivars Ariane, Escalina and Belinka were carried out in 1998 and 1999. PPI trifluralin and EPTC^{+}, at their respective treatment rates, were found to be adequate for use in fibre flax. Pendimethalin treatments meanwhile affected fibre flax populations at emergence, however final dry yields were not always significantly affected. PRE trifluralin, linuron, and the combination of trifluralin + linuron at their respective treatment rates were found to be adequate for use in fibre flax production. In 1998, treatments containing linuron resulted in lower plant populations, which could be attributed to leaching since the experiment was conducted in a sandy soil type. PRE applied pendimethalin resulted in severe stem burning at emergence that resulting in low plant populations, and consequently low final dry yields. POST applied treatments were found to affect flax with different degrees of phytotoxicity but the plants were able to recover from it without affecting final dry yields. The differences in climatic conditions between 1998 and 1999 resulted in differences in plant populations, branching scores, phytotoxicity scores, harvest plant height and harvest yield for all the experiments.

Résumé

En 1998 et 1999, plusieurs traitements d'herbicides pulvérisés à divers moments d'application ont été évalués sur différents cultivars de lin fibreux. Ces études comprenaient des essais en présemis incorporé (PSI) et en prélevé (PRÉ) sur le cultivar de lin fibreux Ariane ainsi que des mélanges en réservoir d'herbicides appliqués en postlevée (POST) sur les cultivars de lin Ariane, Escalina et Bélinka.En PSI, la trifluraline et l'EPTC^{+} ont démontré des résultats adéquats pour la culture de lin fibreux aux doses de traitements respectives. Le pendiméthaline a affecté négativement la population de lin fibreux lors de l'émergence sans pour autant affecter dramatiquement les rendements à la récolte. En PRÉ, la trifluraline, le linuron et la trifluraline + linuron ont démontré des résultats adéquats pour la culture de lin fibreux aux doses de traitements respectives. En 1998, les traitements à base de linuron ont affecté négativement la population de plants de lin fibreux, ce qui pourrait être attribué au lessivage, ces études étant conduites dans un sol léger. En PRÉ, les essais de pendiméthaline ont démontré des brûlures sévères sur la tige lors de l'émergence des plants, ce qui a eu pour effet d'affecter négativement la population et conséquemment les rendements à la récolte. Les traitements de POST ont créé divers taux de phytotoxicité mais les plants de lin fibreux ont bien récupéré et les rendements à la récolte n'ont donc pas été affectés. Tous les essais ont été affectés par les conditions météorologiques différentes entre 1998 et 1999, ces différences se reflètent sur les données concernant les populations de plants, la ramification, les niveaux de phytotoxicité, la hauteur des plants et les rendements à la récolte.

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1. Introduction

Fibre flax (*Linum usitatissimum* L.) is an old crop that has gained renewed interest. This plant contributed tremendously to the fibre industry in pre-Second World War times, but the introduction of synthetic fibres in post-war times, led to the decimation of an industry that once thrived in eastern Ontario and Québec. The interest in this plant is attributed mainly to its renewable source of plant fibres as well as the crop's acceptance by local farmer's as being one with a high potential return with a low cost of inputs as well as a fit into their crop rotation.

1.1. Flax

1.1.1. History

Flax is one of the oldest cultivated crop species along with barley (*Hordeum vulgare* L.) and wheat (*Triticum aestivum* L.) (Schuchert 1997). The plant originated approximately 8000 B.C. in Sumeria and Egypt where it was mainly used for its fibre content (Anonymous 1997a). Its movement to southern Europe by its narrow-leafed perennial wild type ancestor, *Linum angustifolium* Huds., occurred in the early Stone Age approximately 3000 B.C. (Schuchert 1997). Although it was a main source of clothing fibres in ancient civilizations, flax did not become a widely used fibre until the 11th century in southern France, where its use in clothing was thought to also cure prevailing ailments of the times including leprosy (Anonymous 1997a). The crop's northern migration during the Middle Ages reached as far as the Scottish Highlands and Ireland, at which time the selection for both oilseed and fibre traits became apparent. The plant's westward movement to the New World is attributed to Louis Hébert, Canada's first farmer, who grew a plot of flax in the Québec City region in 1617 (Wilkins 1980). Its further progress into the Western Canadian Prairies occurred in 1875 by migrating European settlers (Wilkins 1980). Its good establishment in the highly fertile soil and cool climate rapidly expanded its production for oilseed purposes in the West, while the fibre production remained in the temperate climate of the East. Today, although its total production is lower than pre-war times, fibre flax is a crop still grown worldwide including Russia, Argentina, India, China and parts of Europe (Schuchert 1997). While Canada is the leader in oilseed flax production due to its ideal climate and extensive research, fibre flax has gained renewed interest for its natural fibres for linen and other uses.

1.1.2. Uses and Production

Although linseed flax and fibre flax belong to the same plant species, they are two very different plants with separate growth requirements and final use. As a result of selection for its seed and oil, oilseed flax is a major crop species in western Canada, accounting for 600,000 hectares of the Canadian prairies (Wilkins 1980). It is a short statured plant having numerous capsules, prefers the cool dry climate of the prairies allowing it to produce high oil content, which is rich in linoleic and linolenic acids. Its main uses include oil for varnish, dyes, linoleum, cooking oil and animal feed (Schuchert 1997). Its straw, albeit containing mostly short fibres (tow), is long and supple enough for paper production; mainly currency, cigarette paper and fine stationary (Wilkins 1980). Its rich omega-3 acid content has also been touted as a prevention in hypercholesterolemic atherosclerosis (Prasad 1997) and also is thought to contain anti-cancerous components.

Fibre flax, on the other hand, is a tall statured plant with thick unbranched stems containing a high degree of long fibres and few seed capsules. The plant prefers a more humid climate for growth (Schuchert 1997) and is susceptible to lodging due to high seeding rates. Its main use is as a raw material for the textile industry (Schuchert 1997). With renewed interest by the clothing industry for natural renewable fibres, international designers including Paco Rabane have launched collections made exclusively from linen. Among other uses, flax fibres are being utilized in the automobile industry for the production of car panels. The 1996 E-Class cars by Mercedes-Benz AG contains 17 components which are made from natural products including flax fibers (Winter 1995). Not only are these natural fibres renewable, but also are cheaper, easier to recycle, and lighter than the more traditional plastics they replace.

Historically, linen has been a major source of clothing in the Middle East and Mediterranean regions where it was first cultivated. Its numerous references in the Bible (Wilkins 1980) and the uncovering of fibre flax plant remains in medieval cesspits (Hellwig 1997) are proof of its importance throughout human history. More recently, the Shroud of Turin, reputed to be Jesus Christ's burial garment was analyzed and found to be made of linen fibers. The cultivation of flax for linen was the major textile crop produced until the mid-1800's when cotton became more popular in Europe with the invention of spinning machines allowing easy processing of the fibre (Pomeranz 1994). In Canada, mainly Québec, fibre flax was an important crop up until the Second World War, after which the increasing popularity of cotton and the development of synthetic fibres destroyed the fibre flax industry. On a global basis, fibre flax has had a worldwide decrease in production of almost 50% between 1984 to 1994. The major reason being due to the fall of the Soviet Bloc, the low quality fibres being produced, and poorly mechanized farms (Easson & Molloy 1996).

The increasing popularity of high quality fibre flax for the clothing industry and Québec's suitable climate for production have led to a renewed interest in its development in this Canadian Province. The need for weed management for high quality fibre production has become a priority. As a poor competitor with weeds and volunteer crops, flax must rely on chemical herbicides as the strategy for weed control. Any uncontrolled weeds may not only affect the final yield but also reduce the quality of the fibres from foreign plant fibres. With few registered products here in Québec, the products and potential products employed elsewhere in the world need to be evaluated for their suitability under the present climate and soils in Québec and for crop tolerance.

1.2. Flax-Weed Competition

Flax, whether oilseed or fibre, has been described as a poor competitor with weeds (Friesen *et al.* 1990), produces little shade and utilizes water and soil fertility less efficiently than most weed species (Grünhagen *et al.* 1969). Since it is a crop that is usually preceded by a cereal crop, flax and volunteer cereal competition is as big a concern as weed competition. Not only is the total fibre yield a concern from the effects of competition, but the contamination of foreign plant fibre residues from the weeds will also reduce final quality at scutching (Marshall *et al.* 1995). It is therefore important that weed management systems be carried out early on and keep the other plant populations at a minimum throughout the growing season.

When competition between oilseed flax and volunteer wheat or barley at densities of 30 plants/m^2 was allowed to take place, average seed yield reductions of 50 and 60%, respectively, were observed (Friesen *et al.* 1990). They concluded that the slow and incomplete closure of the flax canopy resulted in minimal volunteer crop shading and as such had a limited effect on volunteer crop mortality. This was however a dryland study, where the expression of competitiveness will be larger. Fibre flax is usually grown in areas where the moisture is more frequent and more constant throughout the growing season. A related study in Scotland on volunteer barley in fibre flax, found that stem dry weights were reduced by 9 to 18% and seed boll dry weights decreased by 7 to 18% over two years at barley densities of 30 plants/m^2 (Marshall *et al.* 1995). This barley density was the economic threshold in fibre flax competition, any higher populations would render the production economically unfeasible.

Green foxtail (*Setaria viridis* (L.) Beauv.) and wild oats (*Avena fatua* L.) are the important troublesome grass weed species in linseed production in western Canada. However, yield reduction of oilseed flax is due to weed densities and not to a particular weed species presence (Friesen 1986). Total removal of all weeds, including broadleaf such as lamb's-quarters (*Chenopodium album* L.) and wild mustard (*Brassica kaber* (DC.) L.C. Wheeler, syn. *Sinapis arvensis*), increased yield by 79% and oil content of the seed by 1%. Any ground cover of weeds surpassing 27% will significantly affect the oil content regardless of dominant weed species (Friesen 1986). Round-leaved mallow (*Malva pusilla* Sm) and dog mustard (*Erucastrum gallicum* (Wild) O.E. Shulz) also compete with oilseed flax reducing final yield. Dog mustard was found to decrease the relative yield of oilseed flax in greenhouse studies as the dog mustard densities were increased (Wall 1997). Meanwhile, field studies found that dog mustard height was lower in related wheat trials than in the flax, further suggesting the lower competitiveness of flax. In wheat, round-leaved mallow densities of 237 plants/m^2 were necessary to reduce wheat yields, while in oilseed flax, only 20 mallow plants/m^2 reduced yields by as much as 33% (Friesen *et al.* 1992).

The effects of the seeding rate can also influence the competitiveness of flax, especially if the crop can emerge prior to the weeds. When the seeding rate of oilseed flax, in the presence of weeds, was increased from 300 plants/ m^2 to 900 plants/m^2, flax seed yield improved by 180 kg/ha, while broadleaf weed biomass yield was reduced by 300 kg/ha and grass weed biomass by 180 kg/ha (Stevenson *et al.* 1996). This higher seeding rate attributed to the increase in the crop growth rate (CGR) and thereby accelerated the rate of resource use by the crop. Furthermore, row spacing of 9, 18 and 27 cm had no effect on oilseed flax seed yield and had minor effects on weed biomass yields in the weedy trials. The applicability of these results for density studies from Saskatchewan on weed populations in Québec are minimal, since the growing conditions differ from Saskatchewan and weed species are more likely to emerge throughout the growing season in Québec.

Whether the competition in flax comes from a volunteer crop or a weed species, flax has been described as having a low competitive advantage as compared to other plant species. The importance of early interference is crucial for high quality and high yield of fibres.

1.3. Chemical Weed Control

Chemical herbicides are the mainstay in weed control in fibre flax. Alternative methods are not well suited to this crop and cannot provide adequate control. Numerous products are presently used to combat weeds in fibre flax and oilseed flax. In Québec, the products available for fibre flax are limited to the products registered in Ontario for oilseed flax. All of these products are post-emergent (POST) treatments, and do not take advantage of the earlier control opportunities with pre-plant incorporated (PPI) and pre-emergent (PRE) products and offer little to no residual activity. There are a variety of products registered in western Canada for use on oilseed flax that are registered for other crops in Québec. These can potentially be employed here if their suitability to fibre flax can be shown. Also, several products available in Europe, which are not registered for any crop in Canada could be examined, but their testing will depend on availability and will require Government approval.

1.3.1. Acetanilides

This family of herbicides contains one product which may have potential in fibre flax production. Propanil (N-(3,4-dichlorophenyl)propanamide) at 0.6 kg/ha in tank mix with sethoxydim (2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydoxy-2-cyclohexen-1-one) has been found not to affect flax development, but control of pigweed (*Amaranthus retroflexus* L.) and lamb's quarters was not accomplished (Chow 1983). In Québec, propanil is not available as an individual product. It comes in a pre-mixed formulation with MCPA (4-chloro-2-methylphenoxy)acetic acid), a widely used herbicide in flax, under the trade name Stampede CM (Ontario Agriculture 1997). This formulation, a ratio of 3.6:1 propanil:MCPA, is registered for spring wheat, barley and oats for the control of foxtails (*Setaria spp.*), lady's thumb (*Polygonum persicaria* L.) and wild buckwheat (*Polygonum convolvulus* L.) (Ontario Agriculture 1997). In tank mix with sethoxydim, control of annual broadleaf plants may be questionable. In western Canada, propanil/MCPA is registered in flax in tank mixes with all available graminicide herbicides.

1.3.2. Aryloxyphenoxypropionates

This family of herbicides contains three registered and one non-registered graminicide for use on flax in Ontario. Diclofop-methyl (methyl 2-[4-(2,4-dichlorophenoxyphenoxy] propanoate]) is registered for use to control emerged annual grasses at 0.71 kg/ha to 0.795 kg/ha (Ontario Agriculture 1997). The higher rate is mainly for control of wild oats. No tank mix options are registered for this product. Since this herbicide is not a commonly used product in Québec, it does not offer any special control measures as compared to other herbicides.

Quizalofop-ethyl (ethyl 2-[4-(6-chloro-2-quinoxalinyloxy)phenoxy] propanoate), offers good annual grass and volunteer cereal control, however it is weak on yellow foxtail (*Setaria glauca* (L.) Beauv.). It is also not registered with any tank mix options. Registered rates are 0.072 kg/ha to 0.144 kg/ha with the highest rate for quackgrass (*Elytrigia repens* (L.) Nevski) control. This product is better suited than diclofop-methyl, since it provides a broader level of control at lower active ingredient rates (Ontario Agriculture 1997).

Fluazifop-p-butyl (butyl 2-[4-[[5-trifluoromethyl)-2-pyridiny]oxy] phenoxy] propanoate) does not control volunteer cereals but provides control of annual grasses and quackgrass. Application rates are 0.075 kg/ha to 0.25 kg/ha with the higher rate for quackgrass control (Ontario Agriculture 1997). Reducing the fluazifop-p-butyl dose to 50 g/ha and mixing with 18 g/ha clethodim provided grass weed control as well as either product alone (Wall 1994a). These rates represent a 20% reduction in total amount of active ingredients required for control of wild oats and green foxtail. Application of this mixture at or after the 3- to 4-leaf stage of grasses controlled late emerging weeds without damaging flax (Wall 1994a). With the addition of bromoxynil (3,5-dibromo-4-hydroxybenzonitrile) and MCPA at 280 g/ha each into the mixture, no observable damage on the flax occurred.

A product not registered in Ontario but potentially useful in fibre flax production is fenoxaprop-p-ethyl ((R)-2-[4-[(6-chloro-2-benzoxazolyl)=oxy]phenoxy]propanoic acid). The Expert Committee on Weeds (ECW) recommended that it be applied at rates of 45 g/ha to 60 g/ha (ECW 1993). Like other herbicides in this family, its function is for the post-emergent control of grasses at the 1- to 6-leaf stage. Tank mix partners for the control of broadleaf weeds must be found for this family of herbicides since split applications of herbicides are not preferred by crop producers.

1.3.3. Benzothiadiazines

This family of herbicides contains one of the most effective broadleaf herbicides, bentazon (3-(1-methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one,2,2-dioxide). It is presently registered for use in oilseed flax at rates of 0.84 kg/ha to 1.08 kg/ha (Ontario

Agriculture 1997) for the control of emerged annual broadleaf weeds, yellow nutsedge (*Cyperus esculentus* L.), Canada thistle (*Cirsium arvense* (L.) Scop.) and suppression of field bindweed (*Convolvulus arvensis* L.). No registered tank-mix options are available, but there is a potential for mixing it with one of the post-emergent graminicides in the aryloxyphenoxypropionate or cyclohexanedione family, at low doses as a rescue treatment for broad-spectrum control of weeds. Fenoxaprop-p-ethyl, fluazifop-p-butyl and quizalofop-ethyl are graminicides that are registered as a tank-mix with bentazon in soybeans (Ontario Agriculture 1997), while sethoxydim and clethodim are registered in the U.S. The phytotoxic effect of these tank mixtures on the fibre flax must be evaluated prior to field use.

Generally, bentazon is used as a split application in flax or as a special rescue treatment for the suppression of perennial weeds including yellow nutsedge, Canada thistle and field bindweed. Post-emergent application of bentazon at 1.44 kg/ha as a split application with PRE-applied trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine) and linuron (N'-(3,4-dichlorophenyl)-N-methoxy-N-methylurea) gave weed control of 84% and 76%, respectively, compared to the hand-weeded check at two different sites (Courtney 1986). Individual bentazon applications at 1.44 kg/ha resulted in 16% and 41% survival of dicot species at two sites (Courtney 1987) and 37% survival of dicot weed species at one site (Courtney 1986) without any observed crop damage. These results indicate that bentazon needs a second chemical compound as either a tank-mix or a split application for the complete control of weeds.

1.3.4. Cyclohexanediones

This family of graminicide herbicides contains two widely used products in flax; sethoxydim and clethodim (2-[1-[[(3-chloro-2-propeny)oxy]imino]=propyl]-5-[2(ethylthio)propyl]-3-hydoxy-2-cyclohexen-1-one). Sethoxydim, alone or in tank mix with broadleaf herbicides is registered at rates of 0.15 to 0.3 kg/ha (Ontario Agriculture 1997). It is effective against most annual grasses, volunteer monocot crops at the low rate, and also against quackgrass at the high 0.5 kg/ha rate. At the low 0.15-kg rate, MCPA has been demonstrated to have antagonistic effects on wild oat control (Chow 1983). Combinations with other broadleaf herbicides; propanil and bromoxynil were shown to provide excellent broad spectrum weed control without crop phytotoxicity.

Clethodim, also registered for flax, however at much lower active ingredient rates of 0.03 to 0.09 kg/ha, has a registered tank mix option with bromoxynil and MCPA (Ontario Agriculture 1997). It is also highly effective against annual grasses, volunteer monocot crops and quackgrass. Hunter (1995) found that clethodim at 20 g/ha when weeds were at the 2- to 3-leaf stage provided excellent control of annual grasses and volunteer cereals. Furthermore, flax was tolerant to clethodim at five times the recommended application rate and plant growth stage at time of application was not affected (Hunter 1995). The performance of clethodim at active ingredient rates five times less than sethoxydim, make it a candidate worthwhile for further research for tank mix options. Lower application rates of this product qualify it for better weed management in integrated weed management systems.

1.3.5. Dinitroanalines

This family of herbicides includes products that are applied as PPI or PRE treatments. All previous herbicides discussed were POST treatments, whereas early applications of season long residual herbicides would be ideally suited for fibre flax production. One herbicide in particular from this family, trifluralin applied in combination with linuron, is already registered as a fall incorporated herbicide in oilseed flax in western Canada for the control of annual grasses and some broadleaf weeds (Manitoba Agriculture 1991) and could prove useful for fibre flax production in Québec. This system of fall incorporation is not suited for Québec due to the climatic differences from western Canada, which would in essence wash away most of the product in early spring. It has been reported that up to 70% of fall incorporated trifluralin in western Canada is lost prior to spring seeding, but performance is generally as good as or better than spring applied trifluralin (Pchajek *et al.* 1983). Taking into consideration large loss observed in the west, cutting the application rate and soil incorporation may prove effective in fibre flax in Québec.

Crop injury from trifluralin is another concern, cultivars differ in their tolerance to trifluralin and injury may occur even on the most tolerant cultivars (Czembor *et al.* 1978). Furthermore, Pchajek *et al.* (1983) found that the fall incorporated trifluralin at 1.12 kg/ha damaged the flax less than the spring applied at 0.84 kg/ha and attributed the result to the better chemical distribution in the soil. Also, control of green foxtail was better in the fall applied treatment, but surviving foxtail plants of the spring applied trifluralin were severely stunted. As for soil residual activity, it was found that the fall applied trifluralin had longer residual activity through to the following growing season than the spring applied (Pchajek *et al.* 1983). Meanwhile, Nawolsky *et al.* (1992) reported that at the 1 kg/ha rate applied in the spring, flax density was reduced by 40%, and an increase in flax branching was observed. Similar results were previously obtained by Nalewaja *et al.* (1987), who found that stand reductions were also caused by trifluralin in the ranges of 50%. However, they also found that shallow seeding of the flax at 1.5 cm into a seedbed treated with a reduced rate of trifluralin (0.8 kg/ha) incorporated deeply (10 cm) improved final crop stand due to the reduction of shoot exposure to the chemical. They concluded that injury to flax from trifluralin may result if the chemical is not evenly distributed in the soil, if the flax is seeded deeper than 3 cm, or if the seeding occurs early in the spring while the seedbed is still cold (Nalewaja *et al.* 1987).

Performance testing of trifluralin (0.96 kg/ha) in fibre flax as PRE treatments with linuron (0.48 kg/ha) have shown that crop response was manifested by a 26% reduction in final weight relative to the hand weeded control in one of three test sites (Courtney 1986). Repeated testing of the mixture the following year at two sites resulted in no measurable difference in final yield loss (Courtney 1987). It was concluded that this mixtureneeded further investigation was needed for use in fibre flax (Courtney 1986). Split treatments of this mixture at lower application rates, with a POST broadleaf herbicide (bentazon or bromoxynil + clopyralid), improved the weed control without affecting final flax yield (Courtney 1986 and 1987).

Pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine) has also been evaluated as a potential herbicide for control of annual grasses and some broadleaf weeds in flax. Results indicate, as with trifluralin, that even incorporation of pendimethalin and shallow seeding (less than 3 cm), were important factors in maintaining a high flax density. Application of 1.1 kg/ha of pendimethalin as a spring incorporation resulted in higher oilseed flax densities and seed yield at both seeding depths (3 cm vs 6 cm) than trifluralin or ethalfluralin (N-ethyl-N-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)) over a two year study (Wall *et al.* 1994b). Also, shallow seeding treatments resulted in an average of 59% higher flax population densities and better seed yields than deep seeding in all treatments over both years. Shoot exposure was attributed as the probable cause for damage. This being the case, pendimethalin was less injurious to flax than trifluralin and ethalfluralin and its feasibility in fibre flax production should also be studied. Furthermore, pendimethalin testing in fibre flax as a PRE treatment at 0.99 kg/ha resulted in no measurable loss in yield at two sites, and dicot weed control was good but grasses were not controlled in one experimental site (Courtney 1987). These findings prove that there is a potential for dinitroanaline use to combat annual weed species as spring PPI or PRE treatments in fibre flax.

1.3.6. Hydroxybenzonitriles

Bromoxynil is presently widely used as a POST herbicide in oilseed and fibre flax. It is registered as pre-mixed formulation with MCPA in a 1:1 ratio at 0.56 kg/ha, therefore 0.28 kg/ha of bromoxynil (Ontario Agriculture 1997). Registered tank mix options are with sethoxydim only. Clethodim may also be suitable as a potential tank mix partner, while the aryloxyphenoxy-propionates have not been looked at as tank mix options in flax.

Field testing of bromoxynil in fibre flax with or without clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) was found to cause some temporary distortion in crop growth but weed control was good after a split-application with a PRE treatment (Courtney 1986). The crop growth distortion after bromoxynil + clopyralid application resulted in no effects on the crop yield (Courtney 1987). Bromoxynil with or without clopyralid was suggested to be further investigated in split-applications with a PRE or an early post (EP) treatment (Courtney 1986 and 1987). ECW (1993) recommended that bromoxynil be used to control smartweed, wild buckwheat and other broadleaf weeds at rates of 0.28 to 0.35 kg/ha before weeds exceed the 3-leaf stage or flax is 8- to 15-cm-tall.

1.3.7. Phenoxys

This family of herbicides includes the widely used MCPA, which is the only highly effective herbicide for the control of wild mustard in flax (Nalewaja 1998). It is registered with bromoxynil in a 1:1 ratio as a POST application or alone at 0.21 to 0.35 kg/ha when flax is 5-cm-tall (ECW 1993) and provides control of most broadleaf weeds. For broad-spectrum control, tank mix option with sethoxydim is presently the best option as a control measure of choice in Québec. MCPA can also be tank mixed with appropriate rates of fluazifop-p-butyl and bromoxynil (ECW 1993) for POST control of weeds. The loss of MCPA, as a herbicide for flax would result in a reduction of production (Nalewaja 1998), leaving bromoxynil as the only registered POST tank mix option for the control of broadleaf weeds.

2,4-D (2,4-dichlorophenoxy acetic acid) has been described as being a phytotoxic phenoxy herbicide to flax (Nalewaja 1998), but for the control of major perennial weed species, 2,4-D is preferred over MCPA. At reduced rates of 0.21 to 0.35 kg/ha, 2,4-D will result in flax damage, but may not be as severe as the inherent yield loss from perennial weed competition of these difficult to control weed species such as Canada thistle and field bindweed (ECW 1993).

1.3.8. Pyridines

Clopyralid is registered for use on oilseed flax in western Canada (Manitoba Agriculture 1991). It provides effective control or suppression of certain annual and perennial broadleaf weeds including Canada thistle, ragweed (*Ambrosia artemisiifolia* L.), dandelion (*Taraxacum officinale* Weber) and wild buckwheat (Ontario Agriculture 1997) as a POST treatment at 0.075 to 0.1 kg/ha. Tank mix options include MCPA at 0.42 to 0.56 kg/ha with sethoxydim at 0.15 to 0.20 kg/ha when flax is between 5-cm and 15-cm-tall (BASF 1997). This tank mix option comes pre-formulated for western Canadian flax producers as a one pass control strategy with no re-cropping restrictions the following year. At the high rate, this combination will control all major grasses, broadleaves and volunteer cereals as well as suppression of Canada thistle and dandelion.

Clopyralid at 50 g/ha mixed with bromoxynil at 240 g/ha resulted in some temporary distortion in crop growth (Courtney 1986 and 1987), but effects on crop yield were not statistically significant (Courtney 1987). The mixture also provided good control of dicot weed species at over 65%, but with the grasses remaining in the plot, not all broadleaf weeds were completely controlled (Courtney 1986). This mixture may, sometimes be weak on pigweed and high densities of ragweed, but the action of the two herbicides may be beneficial if one fails to thoroughly contact the weeds. The broader level of action against certain perennials make it a viable option.

1.3.9. Substituded Ureas

Linuron provides control of many annual grass and broadleaf weed species including foxtail, barnyard grass (*Echinochloa crus-galli* (L.) Beauv.), ragweed, pigweed and triazine resistant biotypes of these weed species (Ontario Agriculture 1997). Its PRE use in soybeans and corn has been limited due to its highly mobile nature in soils with low organic matter content and the potential damage to these crops when heavy rains follow application. The use of linuron on flax was first investigated by Courtney (1986) at 0.75 kg/ha as a PRE in fibre flax. Crop response was noticeable in two of the three sites with an average 63% relative yield to the hand weeded check. This may be attributed to the tendency of linuron to cause damage after a high rainfall or on light soils but no climatic conditions were reported. Linuron at 0.5 kg a.i/ha followed by bromoxynil as a POST at 225 g/ha had on average a 78% relative yield at the same two sites (Courtney 1986).

1.3.10. Sulfonyl-Ureas

In general, sulfonyl-urea herbicides are phytotoxic to flax, however the potential use of this family of herbicides in flax production has been considered. In western Canada, sulfonyl-ureas are not registered for use in oilseed flax but flax was found to be tolerant to chlorsulfuron (2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-

yl)amino]carbonyl]benzenesulfonamide), metsulfuron-methyl (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amoni]sulfonyl]benzoate) and thifensulfuron (3-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl)thiopen-2-carboxylic acid) (Friesen 1988). Ever since then, many producers have been reported to "spike" their herbicide tank-mix with a sulfonyl-urea, usually to improve the control of annual broadleaf weeds such as pigweed (Wall *et al.* 1996).

Chlorsulfuron had gained much attention in Europe for its high efficacy in annual and perennial broadleaf weed control. It is registered in Québec for non-crop lands as a PRE or an EP and once absorbed by the plant it is fully systemic (Ontario Agriculture 1997). Courtney (1986) tested chlorsulfuron at 1.6 g/ha mixed with metsulfuron at 5 g/ha, a product available in Europe and western Canada, as an EP treatment and found that flax was tolerant and weed control was good. A follow up treatment of bromoxynil improved weed control while not affecting the flax (Courtney 1986). This application rate of chlorsulfuron at 1.6 g/ha represents only 1.8% of the registered 90.225 g/ha application rate for perennial weed control in non-crop lands in Québec. Metsulfuron and chlorsulfuron at 15 and 5 g/ha, respectively, were found to cause severe crop stunting (Courtney 1986), indicating the susceptibility of flax to this tank-mix. Derksen *et al.* (1996) found that thifensulfuron at 0.5 to 1.0 g/ha caused visible crop injury and reduced plant height and yield supporting the results of Wall *et al.* (1996) testing thifensulfuron and tribenuron (2-[4-methoxy-6-=methyl-1,3,5-triazin-2yl(methyl) carbamoylsulfamoyl]benzoicacid).

1.3.11. Thiocarbamates

EPTC+ (S-ethyl dipropylcarbamothioate) is registered for use in flax, but no rates or timing are mentioned anywhere (Ontario Agriculture 1997). ECW (1993) listed it as a PPI treatment at rates of 2.8 to 3.6 kg/ha. This chemical is effective against many grass and broadleaf weed species (Ontario Agriculture 1997) and therefore, should be considered as an option for weed management in fibre flax. There are no re-cropping restrictions the following season for this product, and it is a registered tank mix option with trifluralin at reduced rates of 2.4 kg/ha EPTC+ and 0.6 kg/ha trifluralin in beans, thus a potential option for flax.

1.3.12. Other Products

There are numerous products available in Europe that have shown to be quite effective in weed control in flax. Since these chemicals are not available here in Canada, testing for their feasibility in fibre flax production will not be done, however they should be mentioned as potential future reserve candidates, if any of them, were ever registered in Canada.

Haloxyfop (2-[4-(3-chloro-5-trifluoromethyl-2-pyridyloxy)phenoxy]propionic acid), a non-registered herbicide in the aryloxyphenoxypropionate family is not available in Québec but is registered in Europe for use in fibre flax. This product did not reduce the stem height or dry weights of two fibre flax cultivars, Belinka and Regina when applied early at rates of 250 and 500g/ha (Hack *et al.* 1993). Late applications of haloxyfop, when flax was 15-cm-high with the 750 g/ha rate, did reduce stem height and dry weights. Hack et al. (1993) summarized that haloxyfop could be safely applied to these cultivars, even at doses 2 to 3 times the typical commercial rate for annual grass weed control.

Sulcotrione (2-(2-chloro-4-mesylbenzoyl)cyclohexane-1,3-dione), a member of the triketone family which inhibits the formation of 4-hydroxyphenyl-pyruvate-dioxygenase enzyme, is a key POST corn herbicide and through field screening trials revealed excellent selectivity for fibre flax when applied as a PRE (Callens *et al.* 1996). Field trials indicated that sulcotrione applied alone or in combination with lenacil (3-cyclohexyl-1,5,6,7-tetrahydrocyclopentapyrimidine-2,4(3H)-dione) or linuron provided better control of lamb's quarters, eastern black nightshade (*Solanum ptycanthum* Dun. ex DC.), field bindweed and lady's thumb than the reference treatment, linuron with lenacil. It is the only registered PRE treatment for fibre flax in Europe (Callens *et al.* 1996). Since there a no registered PRE treatments for flax here in Québec, sulcotrione could lessen the dependency of POST herbicides while at the same time providing the early control measures with residual activity.

The other major herbicide, which is registered as a PRE in Europe, is lenacil. Applied as a PRE mixed with linuron at a total rate of 750 g/ha, did not affect the fibre flax and provided good weed control (Courtney 1986). Meanwhile, linuron at 125 and 500 g/ha was found to be weak on lamb's quarters but did prove quite effective against most other broadleaf weeds (Callens *et al.* 1996). A follow up with a broadleaf herbicide (bentazon, bromoxynil or MCPA) as a late POST resulted in complete dicot weed control.

1.4. Mechanical Weed Control

No effective system of weed management through mechanical control has yet been established. Researchers have however, looked at the potential of delayed seeding to accommodate pre-seeding tillage to control early flushes of weeds. Hammond (1973) found that by implementing these pre-seeding tillages, oilseed flax yield was decreased by 0.28 bu/Ac for each day delay in seeding after May 1 in North Dakota. In western Canada, cultural practices are employed when feasible, such as pre-seeding cultivations using early maturing flax varieties or fall tillage to induce fall germination prior to winter freeze-up (Flax Council 1997).

1.5. Transgenic Flax

Development of transgenic oilseed flax cultivars specifically resistant to highly effective selective or non-selective herbicides has received considerable attention in western Canada. The introduction of these cultivars resistant to glyphosate (N-(phosphonomethyl)glycine), glufosinate-ammonium (ammonium 2-amino-4-(hydroxymethylphosphinyl)butanoate), or the highly effective sulfonyl-urea family also came with some concerns by scientists about the future of crop production using these cultivars. Among these concerns are the greater use of herbicides, non-sustainable agronomic practices, loss of yield from the addition of a major trait (McHughen *et al.* 1995) and also the potential for cross insertion of the resistant gene into closely related weed species.

The sulfonyl-urea family of herbicides are generally applied at low doses and highly effective in controlling both grass and broadleaf weed species. They have been looked at for their potential use in flax production. The soil residual activity of metsulfuron-methyl to cause damage in flax in Saskatchewan is up to 34 months (McHughen *et al.* 1995). Initial developments of sulfonyl-urea tolerant flax cultivars were specifically aimed at the re-cropping problem of flax after sulfonyl-urea treatment (Wall *et al.* 1996), due to the roots being highly sensitive whereas the foliage can metabolise low quantities of some sulfonyl-ureas (McHughen *et al.* 1995). Insertion of a modified acetolactate synthase (ALS) enzyme from *Arabidopsis* through *Agrobacterium* based gene transfer into flax led to the development of fully resistant flax cultivars. The transgenic lines of oilseed flax were tolerant to field rates of metsulfuron-methyl and triasulfuron (3-(6-methoxy-4-methyl-1,3,5-triazin-2-yl)-1-2-(2-chloroethoxy) phenylsulfonyl urea) without any loss of agronomic traits such as yield reduction (McHughen *et al.* 1995). Meanwhile, Wall *et al.* (1996) found that a transgenic line developed from their laboratory exhibited good tolerance to thifensulfuron at the recommended field rates but the cultivar was not tolerant to tribenuron indicating that the cultivar was not fully cross-resistant. Chikrizova *et al.* (1996) developed a cultivar resistant to chlorsulfuron *in vitro*. Expression of germination and hypocotyl growth in a nourishing media in the presence of chlorsulfuron was better in the transgenic biotype than the susceptible Belinka variety.

The use of non-selective herbicides on transgenic crops has gained much attention in recent years and all the more so has controversy accompanying it. The split among researchers who believe that this type of transgenic crop protection is essential for better crop production in the future and those who are afraid of non-selective herbicide weed resistance development is more apparent than other transgenic crop resistance. Flax resistance to glufosinate ammonium was accomplished through *Agrobacterium* mediated transformation of the phosphinothricin acetyltransferase gene (PAT) (McHughen *et al.* 1995). In preliminary field trials at 600 g/ha, the transgenic cultivar showed small symptoms of herbicidal damage six days after treatment (DAT), but no damage at 68 DAT. Furthermore, important agronomic traits such as seed yield and days to maturity were not affected by insertion of this gene conferring resistance to glufosinate-ammonium (McHughen *et al.* 1995).

It is quite clear that the development of herbicide resistant transgenic flax lines can be easily accomplished with the *Agrobacterium* mediated method. Controversy may be less if fibre flax lines were transformed since the end-product is not a comestible product. Since the relative production of fibre flax is still on a decline on a worldwide basis, this technology is still not a feasible option in improving the weed management of fibre flax.

1.6. Crop Rotation

The use of season long residual group 2 herbicides has dramatically increased over the last 10 years because of their high efficacy on the inhibition of acetolactase synthetase at low active ingredient application rates. Herbicides belonging to the two families of this group of chemical herbicides have been previously shown to be phytotoxic to flax the year following application. The popularity of these herbicides has resulted in resistant biotypes of several broadleaf weed species. The persistence of imidazolinone herbicides is influenced by the degree of adsorption to the soil, soil moisture, temperature and exposure to sunlight. Application of imazethapyr (5-ethyl-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)nicotinic acid) at 200 g/ha reduced flax yield by 40% compared to the hand weeded check the following cropping year at a southern Alberta research site (Moyer *et al.* 1995). This rate equals twice the registered high rate for use on soybeans in Québec, however the climatic conditions of Québec favour a more rapid microbial breakdown with less residue the following crop season. Nevertheless, an overlap with the spray boom or incorrect measurement can pose residual problem the following year.

Flax has been described as being susceptible to the residual activity of some sulfonyl-urea herbicides (Friesen *et al.* 1991), but flax does possess some tolerance to foliar application of several sulfonyl-ureas (Derksen *et al.* 1996) through metabolism to a less-active metabolite (Wall *et al.* 1996). The soil and climatic conditions of southern Alberta are such that the soil persistency of sulfonyl-ureas and damage are greater than most regions of the world (Moyer *et al.* 1990). Triasulfuron was found to reduce flax yield by 17% one year after application of 22 g/ha (Moyer 1995), while greenhouse studies indicated no reductions due to thifensulfuron and tribenuron residues, both herbicides currently used in Québec for broadleaf weed control in cereals. Although, triasulfuron is not available in Québec, there still remains inherent dangers with sulfonyl-urea residues. Without any concrete research data on this commonly employed herbicide, care should be taken when planning the rotation of particular fields.

1.7. Weed Resistance Management

To avoid the development of resistant biotypes of weeds, farmers have the option to rotate their herbicides between different groups from year to year. This task is however limited when the registered available products for one crop all come from the same herbicide group. Such is the case for flax, all registered products for controlling grass weed species are from the aryloxyphenoxypropionates and cyclohexanediones. Both of these belong to the group 1 herbicides having the same mode of action through the inhibition of the acetyl coenzyme-A carboxylase enzyme (ACCase). As long as the herbicide group to combat grasses in the following crop is substituted, the risk of resistance development is low. However, many of these graminicides, especially the aryloxyphenoxypropionates, are also popular herbicides in soybean weed management in Québec.

The use of group 1 herbicides has increased from 15% in 1981 to 50% in 1993 in Manitoba and since 1990 have been used in one out of two fields sprayed with the most intensive use is occurring in flax (Bourgeois *et al.* 1997). The members of this family of herbicides were quickly accepted by farmers due to their high efficacy in controlling wild oats and green foxtail. ACCase resistance was first discovered in a wild oat population in 1990 (Heap *et al.* 1993), a mere 14 years since the first registration of diclofop-methyl. Green foxtail resistance was subsequently reported the following year in 1991. By 1993, resistance was reported throughout the province, and every field case was reported to have had a history of repeated group 1 herbicide use over a period of 5 to 10 years (Morrison *et al.* 1994). Therefore widespread resistance was a case of development and

and not through the transport of resistant weed seeds. Despite the high frequency of group 1 resistance, farmers continue to rely on these herbicides for the control of wild oats and green foxtail. This was shown through the fact that 98% of all flax was treated with a group 1 herbicide in 1993 (Bourgeois *et al.* 1997). We can learn not to forge such a dependence on group 1 herbicides for our fibre flax production by looking for alternative products and maintaining a rotation in the herbicides employed.

1.8. Thesis Objectives

The objectives of this thesis were to assess the suitability of three non-registered pre-plant incorporated herbicides (trifluralin, EPTC, and pendimethalin) and three pre-emerge herbicides (trifluralin, linuron, and pendimethalin) on Ariane as the test flax cultivar, and the combination of three registered post-emerge graminicides (sethoxydim, clethodim, and fluazifop-p-ethyl/fenoxaprop-p-butyl) with four common broadleaf herbicides (MCPA, bromoxynil/MCPA, clopyralid, and clopyralid/MCPA) on three fibre flax cultivars; Ariane, Escalina, and Belinka.

2. Materials and Methods

2.1. Introduction

The research was set in three independent experiments for two growing seasons, 1998 and 1999. The first experiment evaluated non-registered pre-plant incorporated (PPI) herbicides and the second experiment evaluated non-registered pre-emergence (PRE) herbicides using Ariane as the fibre flax cultivar. PPI and PRE herbicides and their rates were selected from prior non-registered research use or from in-field registered use. The third experiment evaluated flax cultivar tolerance to post-emerge (POST) registered tank-mixes, whereby registered in-field use treatments were evaluated on three fibre flax cultivars; Ariane, Escalina and Belinka at 100% (1X) and 200% (2X) of the registered use rates. All experiments included a hand-weeded check and a weedy check in each replicate and were conducted at the Emile A. Lods Agronomy Centre at Macdonald campus of McGill University, Ste-Anne de Bellevue, Québec for both years.

2.1.1. Experiment 1: PPI treatments of non-registered herbicides

Non-registered pre-plant incorporated (PPI) herbicides and their established rates were evaluated for their value on fibre flax cultivar Ariane. Herbicides and their rates used were; trifluralin at 0.60, 0.84, and 1.10 kg a.i./ha, EPTC^{+} at 2.80, 3.20, and 3.60 kg a.i./ha and pendimethalin at 0.84, 0.95, and 1.10 kg a.i./ha. Treatments were randomized in a random complete block design (RCBD) fashion in 1.5 x 5m plots replicated three times in 1998 and 2 x 5m plots replicated three times in 1999.

2.1.2. Experiment 2: PRE treatments of non-registered herbicides

Non-registered pre-emerge (PRE) herbicides and their established rates were evaluated for their value on fibre flax cultivar Ariane. Herbicides and their rates used were; trifluralin at 0.72, 0.96, and 1.10 kg a.i./ha, linuron at 0.36 and 0.48 kg a.i./ha, trifluralin + linuron at 0.72 + 0.36 and 0.96 + 0.48 kg a.i./ha and pendimethalin at 0.99 and 1.10 kg a.i./ha. Treatments were randomized in a random complete block design (RCBD) fashion in 1.5 x 5m plots replicated three times in 1998 and 2 x 5m plots replicated three times in 1999.

2.1.3. Experiment 3: Cultivar tolerance to registered tank-mixes

Eight common tank-mixes and their in-field use rates were evaluated on three fibre flax cultivars; Ariane, Escalina, and Belinka at 100% (1X) and 200% (2X) of their in-field use rates. Herbicides and their rates used were; sethoxydim + MCPA at 0.30 + 0.55 kg a.i./ha and 0.60 + 1.10 kg a.i./ha, sethoxydim + bromoxynil/MCPA at 0.30 + 0.56 kg a.i./ha and 0.60 + 1.12 kg a.i./ha, sethoxydim + clopyralid/MCPA at 0.20 + 0.66 kg a.i/ha and 0.40 + 1.32 kg a.i./ha, clethodim + MCPA at 0.08 + 0.23 kg a.i./ha and 0.16 + 0.46 kg a.i./ha, clethodim + bromoxynil/MCPA at 0.045 + 0.56 kg a.i./ha and 0.09 + 1.12 kg a.i./ha, clethodim + clopyralid at 0.08 + 0.13 kg a.i./ha and 0.16 + 0.26 kg a.i./ha, fluazifop-p-butyl + fenoxaprop-p-ethyl + bromoxynil/MCPA at 0.04 + 0.015 + 0.23 kg a.i./ha and 0.08 + 0.03 + 0.46 kg a.i./ha and fluazifop-p-butyl + fenoxaprop-p-ethyl +MCPA at 0.08 + 0.015 + 0.17 kg a.i./ha and 0.16 + 0.03 + 0.34 kg a.i./ha. Treatments were randomized in a random complete block design (RCBD) fashion in 1.5 x 5m plots replicated three times in 1998 and 2 x 5m plots replicated three times in 1999.

2.2. Seeding

Certified seeds of variety Ariane, Belinka, and Escalina were obtained annually from the fibre flax processing plant, Gilflax, in Valleyfield, Québec. All trials were seeded using a Hassia® seeder with 8-cm-row spacing at seeding rate settings of 35 for Ariane and Belinka and 45 for Escalina. This resulted in a seed delivery rate of 120 kg/ha and 130 kg/ha, respectively, to obtain the desired plant population of 1500 to 1800 plants/m^2. The seeding depth was 4.5 cm deep. In 1998, all experiments were seeded on May 29 on hayfield return ranges at the Emile A. Lods Agronomy Centre with a chisel-plow tillage in the spring without a herbicidal burn-down. In 1999, all experiments were seeded on May 21 on soybean return ranges at the Emile A. Lods Agronomy Centre using conventional tillage practices. The PPI and PRE experiments were conducted on a sandy loam soil in 1998 and in a clay soil in 1999. The POST experiment was conducted in a clay soil in 1998 and a clay-loam in 1999. A table describing the exact soil type proportions of the land ranges used is described in Appendix A. A fertilizer regime of 50 kg/ha of 0-20-20 was applied and worked into the top 4cm of the soil prior to seeding. PPI treatments were applied and incorporated into the top 3 cm with a cultivator 24 hours prior to seeding in both 1998 and 1999. Monthly mean temperature and rainfall data for the Ste-Anne de Bellevue area was obtained from Environment Canada and is tabulated on a monthly basis in Appendix B.

2.3 Herbicide Application

All herbicide treatments were mixed within 24 hours of application with the pre-determined amount of herbicide mixed with water to spray all three replicates of each treatment at 110% total volume to allow for spray solution to fill the sprayer hose and boom prior to application. A hand-held CO_2 pressurized sprayer was employed during both years with a spray width of 1.5m in 1998 and 2m in 1999. A spray solution delivery rate of 200 l/ha with 275-kPa pressure was employed for all herbicide treatments in both years. Sprayer nozzle types employed were TeeJet brand, 8002 flat fan type, held at a 25° forward angle off the right angle of the spray boom to allow for maximal spray coverage at application. The sprayer was calibrated prior to spraying the treatments by measuring all delivered volumes of all four nozzles. Nozzles not within a 5% delivery rate of the others were replaced with new ones. Treatment applications were split into two timings. The first set of treatments for the PPI and PRE experiments were applied within 24 hours prior and after seeding respectively for both years corresponding to May 28 in 1998 and May 20 in 1999. The second set of treatments was applied on the same day for all POST experiment treatments when the flax was between 5 cm and 12 cm in height. This timing corresponded to June 26 in 1998 and June 13 in 1999. A hand-weeded check and an untreated weedy check were included in each replicate of each experiment. The weed free check was weeded on a weekly basis until crop establishment.

2.4. Data Collection

All experiments were rated on their respective treatment tolerance to the herbicide employed. The focus of these experiments was not to evaluate the performance of the herbicides on the weeds but rather the herbicidal effect on the crop. Each experiment was followed throughout the growing season for specific data collection or successive data collection.

All treatments were rated for plant population at emergence in 100-cm^2 quadrats three times in each replicate. The plant population collection occurred after treatment application in the PPI and PRE experiments and prior to treatment application in the POST experiment. When the flax attained 30 cm in height, all three experiments were evaluated for branching percentage. A visual evaluation was employed based on the whole plot using a scale of 0 to 90 with 10 as an interval. A phytotoxicity rating was taken 7 days after herbicide application in the POST experiment only. The rating was based on a scale of 0 to 100, where 0 is no phytotoxic effect and 100 a is complete phytotoxic effect and symptoms observed were; leaf burning, plant stunting, severe branching and growing point burning. Plant height was measured at harvest for all experiments. At harvest, all three replicates of each treatment were sampled for a 0.25 m^2 quadrat sample that was harvested and weighed. These samples were then hung in an air dryer at the Seed Farm, Macdonald Campus of McGill University for approximately one week to allow complete drying and dry weight was taken.

2.5. Data Analysis

All data was analysed using SigmaStat (Anonymous 1997b) for analysis of variance and normality. The homogeneity of variances was determined using Bartlett's test of variances (Steel and Torrie 1980), the resulting Chi-square values were used as the indicators of homogeneity of variances for all data collected and presented as either separate or combined data sets for year or treatment. Data for PPI an PRE plant populations, branching scores, harvest plant heights, and harvest weights were analyzed in a one-way ANOVA, whereas POST data for plant populations, branching scores, phytotoxicity scores, harvest plant heights, and harvest weights were analyzed in a two-way ANOVA. Comparisons of means among treatments for mean plant population, mean phytotoxicity scores, mean branching scores, mean harvest plant heights and mean harvest dry weight were done using the Tukey test. Non-parametric data, which were in the 0 to 30% range, were transformed by square root transformation prior to analysis. Detailed results of the analyses of variance are summarized in Appendices C to E.

3. Results and Discussion

3.1. Experiment 1: Evaluation of PPI herbicides for suitability in fibre flax use

This experiment was successfully carried out in both 1998 and 1999. The difference in growing conditions between 1998 and 1999 was noted in the sharp differences in plant population, stem branching, and dry yields, but the plant growth rates between the two years remained constant.

Population

Analysis of variance indicates significant difference ($P<0.001$) in 1998 and no difference ($P>0.050$) in 1999 among treatment means (Table 3.1). The plant population means for the 1999 treatments were well below the desired 1500 to1800 plants/m^2 range, whereas the 1998 plant population treatment means were generally within this desired range. The mean plant population for all treatments was 1560 plants/m^2 in 1998 and 560 plants/m^2 in 1999. The continuing dry conditions after seeding in 1999 severely affected seedling emergence and resulted in a 64% lower final plant population than in 1998. A germination test of the Ariane seeds used in 1999 was done following the noticeable low plant populations. Results from the germination test showed a 92% germination rate indicating that the seeds used were of high quality. Dry conditions were therefore the main reason for the low plant populations observed in 1999.

In 1998, the weedy check treatment had the highest mean plant population of 2200 plants/m^2, and was comparable to the weed-free check and the 3.20 $EPTC^+$ treatment rate (Table 3.1). The lowest mean plant population was observed in the 1.10

Table 3.1. The effect of pre-plant incorporated herbicide treatments on flax population, branching, height, and dry weight.

Treatment	Rate (kg a.i./ha)	Population (plants/m^2)		Branching (%)	Plant Height (cm)	Dry weight (g/m^2)	
		1998	1999	1998-1999	1998-1999	1998	1999
Weed Free	-	1933 ab	670	20 b	84	1052	805.2 ab
Weed Check	-	2200 a	670	30 ab	89	717.2	396 c
Trifluralin	0.60	1567 cd	630	32 ab	82	1138.8	1054.8 a
Trifluralin	0.84	1200 de	400	37 a	85	894.8	726.8 b
Trifluralin	1.10	1667 b-d	600	27 ab	90	1062.8	880 ab
EPTC[+]	2.80	1600 b-d	570	20 b	87	874.8	860 ab
EPTC[+]	3.20	1733 a-c	600	22 b	83	1017.2	1080 a
EPTC[+]	3.60	1697 b-d	530	22 b	81	878.8	912 ab
Pendimethalin	0.80	1267 cd	500	28 ab	87	1128	932 ab
Pendimethalin	0.95	1367 cd	600	30 ab	88	977.2	749.2 b
Pendimethalin	1.10	933 e	400	32 ab	86	884	854.8 ab

In a column, means followed by a common letter are not significantly different by Tukey's HSD (P<0.050).

Bartlett's test for homogeneity of variances:	Population	Chi-Square = 5.24 *
	Branching	Chi-Square = 0.13 ns
	Plant Height	Chi-Square = 0.00 ns
	Dry Weight	Chi Square = 11.96 **
	Where:	** - significant at 1%
		* - significant at 5%
		ns – not significant

pendimethalin treatment rate with a plant population of 933 plants/m^2 and was comparable to the 0.84 trifluralin treatment rate. In 1999 the weed-free check and weedy-check treatments resulted in the highest mean plant populations at 670 plants/m^2, whereas the 1.10 pendimethalin and 0.84 trifluralin treatment rates were found to have the lowest mean plant population at 400 plants/m^2.

All trifluralin treatment rates resulted in comparable plant populations in both years. The mean plant population of the 0.60 and 0.84 trifluralin treatment rates in both years are similar to the findings of Nalewaja *et al.* (1987), Pchajek *et al.* (1983) and Nawolsky *et al.* (1992), where increasing rates of trifluralin resulted in lower mean plant populations. The mean plant population response from the 1.10 trifluralin treatment rate, however goes against these findings in both years and cannot be explained.

The EPTC$^+$ treatments resulted in comparable plant populations in both years. The low mean plant populations of all pendimethalin treatments can in part be explained by the nature of this herbicide and its selectivity. The mode of action for this herbicide is through the action of inhibition of cell division in the roots, and high levels of pendimethalin may have resulted in root mass reduction, thereby reducing the plant population. Wall (1994) reported that pendimethalin treated flax at 1.10 kg a.i./ha by PPI resulted in a 59% density reduction when flax was seeded at 6 cm as compared to seeding at 3 cm. He further reported that trifluralin affected plant densities more than pendimethalin at both seeding depths. The seeding depth used in the experiment was 4.5 cm indicating a relationship between seeding depth and plant population and the 1.10 pendimethalin treatment mean plant populations were lower than the 1.10 trifluralin treatment mean plant populations in both years.

Branching

Plant branching scores were taken in both years to evaluate branching 14 days after emergence (DAE), which corresponded to the flax being at least 30 cm in height when branching is evident. The data is tabulated as combined means for both years (Table 3.1) and treatments were found to significantly differ ($P<0.001$) among each other. The 0.84 trifluralin treatment rate resulted in the highest mean combined plant branching score of 37% and is comparable to the mean branching scores of the weed check, the two other trifluralin treatment rates, and all pendimethalin treatment rates. The weed-free treatment and the 2.80 $EPTC^{+}$ treatment resulted in the lowest mean combined branching score of 20% and were comparable to the weed check treatment, the 0.60 and 1.10 trifluralin, the 3.20 and 3.60 $EPTC^{+}$, and all pendimethalin treatment rates.

There is a perceived negative relationship between plant population and plant branching. As the emerged plant population decreases, the branching score increases and was especially obvious with the low plant populations of 1999. With the increased branching, a reduced yield effect was noticed due to the increased number of branches acting as separate plants. This can however, reduce the quality of the fibre by obtaining a lower ratio of short fibres to long fibres from the branched plants. The higher branching percentage of the weed check compared to the weed free is difficult to interpret. Although the populations for both are comparable for 1998 and 1999, there was a difference between the two treatments. All treatments resulted in comparable mean combined branching scores within their respective treatment rates. The trifluralin 1.10 treatment rate did not follow the pattern of increasing branching due to a higher treatment rate. Nawolsky *et al.* (1992) reported that increasing the trifluralin rate resulted in increased branching. In both years, this treatment had the highest branching score of the three treatment rates.

Harvest Plant Heights

Harvest plant heights were tabulated as combined means of both years (Table 3.1) Average harvest plant heights of all treatments were 15% shorter (12.8 cm) in 1999 than 1998. The high heat and drought stress encountered in the 1999 growing season as well as low plant population of that year which reduced the intra-specific competitiveness of flax that resulted in a tendency to branch instead of growing tall were the main reasons for the lower plant heights. The low water availability throughout this growing season also contributed to plant stunting. There was no statistical difference ($P>0.050$) among mean harvest plant heights. The 1.10 trifluralin treatment rate resulted in the highest mean harvest plant height (90 cm) and the 3.60 EPTC^{+} treatment resulted in the shortest (81 cm).

The trifluralin treatments showed the greatest harvest plant height variability (7 cm) and had an increasing mean harvest plant height as the treatment rate increases. Nawolsky *et al.* (1992) reported that flax had a higher crop growth rates (CGR) when treated with trifluralin than untreated. This CGR however, was expressed as a yield accumulation on an area basis per day. Although this study concentrated on actual plant heights, it was noticed with trifluralin that an increase in treatment rate led to increased final plant height. Most treatments also gave taller plants than the weed free check plants at harvest.

Harvest Dry Weights

Plant harvest dry weights were recorded for all treatments in both years (Table 3.1). Harvest was carried out on September 2nd in 1998 corresponding to 96 days after seeding (DAS) or 74 DAE, and on August 27th in 1999 corresponding to 98 DAS or 81 DAE. Although the fresh weight was recorded, it is not a good indicator of yield since some treatments may have slowed down or enhanced the maturity of plants and is just used to determine average dry matter percentage at harvest. The average calculated dry matter content of the flax at harvest in 1998 and 1999 was 34% and 40%, respectively. The higher dry matter content was due to the dry conditions of 1999 where the flax plants were forced to maturity.

The dry weights significantly differed ($P<0.001$) among treatments in 1999 only. The dry weight was found to be only 13% lower in 1999 even with the 36% lower mean plant population of all the treatments than in 1998. The heavy branching of 1999 compensated for the low populations observed during that year.

In 1998, the weed-check had the lowest mean dry weight of 717.2 g and the 0.60 trifluralin treatment rate resulted in the highest dry yield at 1138.8 g. In 1999, variation among treatments resulted in weed check having the lowest dry yield of 396 g and the 3.20 EPTC$^+$ rate resulted in the highest mean dry weight and comparable to the mean dry weights of the weed-free check, 0.60 and 1.10 trifluralin treatments, 2.80 and 3.60 EPTC$^+$ and 0.80 and 1.10 pendimethalin treatment rates.

The 0.60 and 0.84 trifluralin treatment rates resulted in comparable dry weights in 1998. This supports the findings of Nalewaja *et al.* (1987), Pchajek *et al.* (1983) and Nawolsky *et al.* (1992) that increased trifluralin rate reduced mean plant populations but did not have any impact on yield. In 1999, the 1.10 trifluralin treatment rate resulted in dry yields that followed the observed plant densities of this study but negated the predicted plant densities and yields. The 3.20 EPTC$^+$ treatment rate resulted in the highest dry weight among all EPTC$^+$ treatment rates. The pendimethalin treatments showed a decreasing dry yield as the rate was increased in 1998, but in 1999, the 0.95 pendimethalin treatment rate had the lowest dry yield and all three rates were significantly different ($P<0.001$).

3.2. Experiment 2: PRE treatments of non-registered herbicides

This experiment was successfully carried out in both 1998 and 1999. The difference in growing conditions between 1998 and 1999 was noted in the sharp differences in plant population, stem branching, dry weight and harvest plant heights.

Plant Population

Analysis of variance indicated significant difference ($P<0.001$) among plant population treatment means for both years (Table 3.2). The plant population means for the 1999 treatments were well below the desired 1500 to 1800 plants/m^2 range, as were most of the 1998 treatment means. The mean plant population for all treatments was 1210 plants/m^2 in 1998 and 520 plants/m^2 in 1999. The continuing dry conditions after seeding in 1999 severely affected seedling emergence and resulted in a 43% lower final plant population than in 1998. A germination test of the Ariane seeds used in 1999 was done following the noticeable low plant populations. The results of this germination test indicated high quality seed with a 92% germination rate and therefore the dry conditions were subsequently singled out as the main reason for the low plant populations of that year.

In 1998, the weedy free check treatment had the highest mean plant population of 1730 plants/m^2, and was comparable to the mean plant populations of the weed free check, and all trifluralin treatments (0.60, 0.84 and 1.10 kg a.i./ha). The 1.10 pendimethalin treatment had the lowest mean plant population of that year at 630 plants/m^2. In 1999, the weed free check treatment had the highest mean plant population at 670 plants/m^2 and was comparable to the population means of all other treatments

Table 3.2. The effects of pre-emergence herbicide treatments on flax population, branching, height, and dry weight

Treatment	Rate (kg a.i./ha)	Population (plants/m^2)		Branching (%)	Plant Height (cm)	Dry weight (g/m^2)	
		1998	1999	1998-1999	1998-1999	1998	1999
Weed Free	-	1730 a	570 a	28 b-d	83 a	1026.8 a	604 a-c
Weed Check	-	1400 a-c	670 a	21 cd	88 a	894.8 a-c	425.2 c-d
Trifluralin	0.72	1630 ab	530 ab	20 d	81 a	918.8 a-c	549.2 a-d
Trifluralin	0.96	1570 ab	570 a	32 b-d	82 a	957.2 a	621.2 a-c
Trifluralin	1.10	1330 a-c	530 ab	25 cd	84 a	912 a-c	681.2 a
Linuron	0.36	1070 cd	600 a	28 b-d	83 a	626.8 bc	704 a
Linuron	0.48	970 cd	470 ab	33 a-c	84 a	798.8 a-c	669.2 ab
Trifluralin + Linuron	0.72 + 0.36	1170 b-d	530 ab	25 cd	85 a	938.8 ab	653.2 ab
Trilfuralin + Linuron	0.96 + 0.48	1070 cd	600 a	33 a-c	87 a	1097.2 a	728 a
Pendimethalin	0.99	770 d	330 bc	40 ab	64 b	489.2 c	353.2 cd
Pendimethalin	1.10	630 e	270 c	45 a	61 b	481.2 c	304 d

In a column, means followed by a common letter are not significantly different by Tukey's HSD (P<0.050).

Bartlett's test for homogeneity of variances:	Population	Chi-Square = 10.36**
	Branching	Chi Square = 1.03 ns
	Plant Height	Chi-Square = 2.64 ns
	Dry Weight	Chi Square = 4.52 *

Where:
** - significant at 1%
* - significant at 5%
ns – not significant

treatments. The 1.10 pendimethalin treatment resulted in the lowest mean plant population in that year at 270 plants/m^2 and was comparable to the 0.99 pendimethalin treatment mean at 330 plants/m^2.

These two population means observed in the 1999 pendimethalin treatments represent 63% and 52% of the trial averages. Courtney (1987) reported average plant densities of 1211 and 1982 plants/m^2 at two sites, but no individual treatment density for pendimethalin 0.99-kg a.i./ha, which was included, was discussed. The PRE applied pendimethalin on the soil surface resulted in an observed basal callus formation (hypocotyl enlargement) of the emerged flax seedlings. This is a symptom often encountered in PRE applied pendimethalin in soybean crops and was observed by Courtney (1986) with a trifluralin + linuron treatment. Glover *et al.* (1997) reported that certain soybean cultivars were more susceptible to hypocotyl enlargement, lodging, and stem breakage following a treatment with pendimethalin. Meanwhile, Struckmeyer *et al.* (1976) reported hypertrophy and hyperplasia of stem cells from pendimethalin in certain soybean cultivars. These symptoms are occasionally observed in soybeans and were also encountered in PRE treated pendimethalin flax trials whereby, it is thought that the inhibition of the tubulin protein formation by the pendimethalin resulted in lower flax seedling emergence and stem damage of the emerged seedlings.

The 1.10 trifluralin treatment had the lowest plant population among trifluralin only treatments in 1998 at 1330 plants/m^2 while the 0.72 and 0.96 rates were within the desired plant population range. These populations were slightly lower than those observed in the 1998 PPI treatments (Table 3.1) where similar treatment rates were employed. Courtney (1987) did not report any effects of the trifluralin 1.10 kg a.i/ha treatment rate on the plant population, but the average trial population means was 1211 and 1982 plants/m^2 at the two trial locations using the same Belinka seed at identical seeding rates. The 1999 trifluralin only treatments had an average 63% lower plant population due to the extended dry period after seeding. In 1999, the 0.72 and 1.10 trifluralin treatment rates gave the lowest plant density at 530 plants/m^2. In the 1999 PPI treatments however, this 1.10 rate was found to have the highest density (Table 3.1).

Linuron plant densities were below the trial average for both years except for the 0.36 rate in 1999. This rate had higher plant densities in both years than the 0.48 rate. It is assumed that the high linuron rate led to a reduction in mean plant population due to herbicidal leaching into the root zone where root development would be inhibited. When in combination with trifluralin, linuron at the equivalent rates had higher plant densities except for the 0.36 rate in 1999. The linuron and the combination of linuron and trifluralin did result in acceptable plant density levels when comparing against the trial averages of both years. These densities however, are the trial averages including pendimethalin and can be misinterpreted due to the low observed densities of this treatment. Both pendimethalin treatments should be discounted when interpreting the data due to its unsuitability for pre-emergence application. Courtney (1986), reported trial population density averages of 2337, 1251 and 1396 plants/m^2, but no explanation for the causes of density variance between locations was given. There was however, a different soil type at the two lower plant densities than that of the higher densities as well as no individual treatment density for linuron at 0.75 kg a.i./ha and trifluralin + linuron at 0.96 + 0.48 kg a.i./ha was discussed.

Branching

Plant branching scores were taken in both years to evaluate the branching 14 days after emergence (DAE) which corresponded to the flax being at least 30 cm tall. The data is tabulated as combined means for both years (Table 3.2). Analysis of variance resulted in a significant difference (P<0.001) among mean branching scores for the combined data set. The 1.10 pendimethalin treatment rate resulted in the highest mean combined branching score of 45% and was comparable to the mean scores of the 0.99 pendimethalin, 0.48 linuron, and 0.96 trifluralin + 0.48 linuron treatments. The 0.72 trifluralin treatment resulted in the lowest mean combined branching score of 20% and was comparable to the mean scores of the weed-free, weed check, 0.96 and 1.10 trifluralin, 0.36 linuron, and 0.72 trifluralin + 0.36 linuron treatment rates.

Harvest Plant Heights

Plant heights were tabulated as combined means for both years (Table 3.2). Average harvest plant heights of all treatments were 19% shorter (15.3 cm) in 1999 than 1998. The high heat and dry conditions as well as the low plant populations of 1999, which resulted in a tendency to branch rather than grow tall are the main reasons for these differences in plant heights. The combined data resulted in a significant difference (P<0.001) among plant height means. The weed check resulted in the highest mean harvest plant height at 88 cm and was comparable to all other treatments except for the pendimethalin treatments, for which the 1.10 treatment rate resulted in the lowest mean harvest plant height of 61 cm.

The trifluralin treatments, as was observed in the PPI treatments (Table 3.1), had an increasing mean harvest plant height as treatment rate was increased which resulted in no variation. The linuron and trifluralin + linuron treatments also resulted in no difference among treatment means and showed potential for use in fibre flax production.

Harvest Dry Weights

Plant harvest dry weights were recorded for all treatments in both years (Table 3.2). Harvest was carried out on September 2nd in 1998 corresponding to 96 days after seeding (DAS) or 74 DAE, and on August 27th in 1999 corresponding to 98 DAS or 81 DAE. Although the fresh weight was recorded, it is not a good indicator of yield since some treatments may have slowed down or induced the maturity of the flax and was just used to determine average dry matter percentage at harvest. The average calculated dry matter content of the flax at harvest in 1998 and in 1999 was 34% and 40%, respectively. The higher dry matter content was due to the dry conditions of 1999 where the plants were forced to maturity.

Analysis of variance indicated that there is a significant difference ($P<0.001$) among treatment dry weights in both years. In 1998, the 0.96 trifluralin + 0.48 linuron treatment rate resulted in the highest mean dry weight of 1097.2 g and was comparable to the dry weights of the weed-free, weed check, all trifluralin treatments (0.72, 0.96 and 1.10 kg a.i./ha), 0.48 linuron, and the 0.72 trifluralin + 0.36 linuron treatments. The 1.10 pendimethalin treatment rate resulted in the lowest dry weight and was comparable to the dry weights of the weed check, 0.72 and 1.10 trifluralin, and both linuron treatments (0.36 and 0.48 kg a.i./ha). In 1999, the 0.96 trifluralin + 0.48 linuron treatment resulted in the highest mean dry weight of 728 g and was comparable to the dry weights of all treatments except for the weed-check and both pendimethalin treatments (0.99 and 1.10 kg a.i./ha). The 1.10 pendimethalin treatment resulted in the lowest dry weight of 304 g and was comparable to the dry weights of the weed check, 0.72 trilfuralin, and 0.99 pendimethalin treatment rates.

Courtney (1987) reported that the PRE applied pendimethalin at the 0.99 kg a.i./ha application rate resulted in dry yields of 93 and 99% of the unsprayed checks at the two locations 131 and 107 DAS, respectively. These observed yield results for pendimethalin indicated its potential use in fibre flax as a PRE treatment, however the observed effects of this treatment on plant densities in this experiment suggests that pendimethalin is not a feasible PRE weed control option for fibre flax production in Québec.

The linuron treatments were found to have dry yields below the experimental average in 1998 but above the experimental average and the weed-free treatment in 1999. Courtney (1986) reported linuron dry yields at the 0.75 kg a.i./ha rate of 102, 61 and 66% of the hand-weeded check at 95, 94, and 104 DAS, respectively. There was no explanation given for yield differences among the three locations, however the high application rate as well as the change in soil type in the lower yielding sites may have resulted in linuron leaching into the soil, thereby, affecting flax root development. The present experiment was conducted on a sandy loam in 1998 and may in part explain the lower plant densities where linuron leaching may have affected the plant densities and as a result affected dry yield of that year. The 1999 experiment was conducted on a clay soil which would have reduced linuron leaching, thereby, limiting its effects on plant densities. Linuron has a narrow spectrum of weed control and it exerts its effects mainly on broadleaf weeds, thus it would require to be employed in combination with another chemical herbicides.

The trifluralin treatments were found to produce the most consistent dry yields over the two growing seasons with the exception of a below experimental average dry yield at the 0.72 rate in 1999. Courtney (1987) reported dry yields from trifluralin at the 1.10 rate of 88 and 118% of the unsprayed check 131 and 107 DAS, respectively. Trifluralin has a narrow spectrum of weed control and it exerts its effects mainly on grass weed species, thus it would need to be employed in combination with another chemical herbicide.

The trifluralin + linuron treatments had the highest yield in both years with the 0.96 + 0.32 kg a.i./ha treatment rate. However, since the experiment was carried out on a sandy loam soil type in 1998, it can be assumed that the linuron leached into the root system and affected the plant densities, thereby affecting the dry yield. Courtney (1986 and 1987) reported dry yields from trifluralin + linuron treatments at the 0.96 + 0.48-kg a.i/ha rate of 100, 74 and 97% of the weed-free check 95, 94 and 104 DAS, respectively, in 1986 and 97 and 128% of the unsprayed check 131 and 107 DAS, respectively, in 1987. The 74 and 97% yields in 1986 were conducted on a different soil type and can be assumed that some damage from linuron leaching may have occurred. This treatment is the most suitable treatment for a PRE application strategy in fibre flax production in Québec.

3.3 Experiment 3: Fibre flax cultivar tolerance to herbicide tank-mix combinations

The POST cultivar tolerance experiment was carried out successfully in both 1998 and 1999. In addition to the plant population, branching, harvest plant height and harvest dry weight, a visual phytotoxic effect score was taken for all treatments seven days after treatment (DAT) application. A noticeable difference in plant population, phytotoxicity scores, branching scores, harvest plant heights and dry weights were observed between 1998 and 1999. The hot and dry climatic conditions after plant emergence of 1999 (Appendix B) were the main reasons for these differences.

Population

In 1998, the plant populations among the treatments within cultivars were not significantly different ($P>0.050$) but there was a significant difference among the cultivars used ($P<0.001$). All three cultivars were found to be within the desired 1500 to 1800 plants/m^2 in 1998, however, Belinka gave the lowest mean plant population of 1555 plants/m^2. Observed mean plant populations were 1850 plants/m^2 with a standard error of 22 for Ariane, 1789 plants/m^2 with a standard error of 29 for Escalina, and 1555 plants/m^2 with a standard error of 19 for Belinka where the mean plant population of Ariane and Escalina were comparable.

In 1999, the plant population among treatments within cultivars were not significantly different ($P>0.050$) but there was a significant difference among cultivars ($P<0.001$). The average plant population for all three cultivars was 32% less than that of the 1998 population. This was mainly attributed to the dry growing conditions following seeding. Belinka again gave the lowest mean plant population at 504 plants/m^2 with a standard error of 11, Ariane had a mean plant population of 561 plants/m^2 with a standard error of 12, and Escalina had a mean plant population of 578 plants/m^2 with a standard error of 20. Ariane and Escalina cultivars were comparable in mean plant populations, but Belinka was statistically different ($P<0.001$).

Phytotoxicity

A visual phytotoxicity rating was taken 7 DAT to evaluate the effects of the treatments and treatment rates on the aerial flax parts of the three different cultivars. The Bartlett's test for homogeneity of variances resulted in a Chi-Square of 24.09 and as such the data are presented separately by year and by cultivar (Tables 3.3 and 3.4). There was no significant differences among cultivars ($P>0.050$) in 1998 but they were found to differ ($P<0.001$) in 1999. Treatments were found to differ ($P<0.001$) both years. Overall, cultivar phytotoxicity scores were found to be greater among most treatments in 1999 due to the high temperature at treatment application and continued dry unfavourable growing conditions following treatment application.

In 1998, the weed-check resulted in the lowest branching scores of 0% among all three cultivars (Table 3.3) while the sethoxydim + bromoxynil/MCPA 2X treatment resulted in the highest mean phytotoxicity in the Ariane and Escalina cultivars at 30 and 32%, respectively and the sethoxydim + clopyralid/MCPA in the Belinka cultivar at 52%. In 1999, when branching was generally higher, the lowest mean phytotoxicity rating was observed in many treatments in all three cultivars (Table 3.4), while the highest mean phytotoxicity was 43% by the clethodim + bromoxynil/MCPA 2X treatment rate in the

Table 3.3: Effect of post-emerge herbicide tank-mix combination treatments on plant visual phytotoxicity percentage means (7 DAT) on three fibre flax cultivars (1998).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Weed Free	-	3 bc	7 bc	7 b
Weed Check	-	0 c	0 c	0 b
Sethoxydim + MCPA	0.30 + 0.55	0 c	7 bc	10 b
Sethoxydim + bromoxynil/MCPA	0.30 + 0.56	3 bc	0 c	3 b
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	0 c	5 bc	10 b
Clethodim + MCPA	0.08 + 0.23	0 c	5 bc	2 b
Clethodim + clopyralid	0.045 + 0.56	0 c	5 bc	0 b
Clethodim + bromoxynil/MCPA	0.08 + 0.13	15 a-c	3 bc	0 b
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.04/0.015 + 0.23	2 bc	3 bc	2 b
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	5 bc	5 bc	3 b
Sethoxydim + MCPA	0.60 + 1.10	12 a-c	27 ab	18 b
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	30 a	32 a	7 b
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	12 a-c	20 a-c	52 a
Clethodim + MCPA	0.16 + 0.46	2 bc	0 c	0 b
Clethodim + clopyralid	0.09 + 1.12	7 a-c	0 c	0 b
Clethodim + bromoxynil/MCPA	0.16 + 0.26	25 ab	8 a-c	12 b
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.16/0.03 + 0.46	5 bc	7 bc	7 b

Table 3.3. (continued). Effect of post-emerge herbicide tank-mix combination treatments on plant visual phytotoxicity percentage means (7 DAT) on three fibre flax cultivars (1998).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	3 bc	8 a-c	7 b

In a column, means followed by a common letter are not significantly different by Tukey's HSD ($P<0.050$).

Bartlett's test for homogeneity of variances: Phytotoxicity Chi-Square = 24.09**

Where: ** - significant at 1%

Table 3.4: Effect of post-emerge herbicide tank-mix combination treatments on plant visual phytotoxicity percentage means (7 DAT) on three fibre flax cultivars (1999).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Weed Free	-	0 e	0 e	3 c
Weed Check	-	0 e	0 e	0 c
Sethoxydim + MCPA	0.30 + 0.55	0 e	0 e	0 c
Sethoxydim + bromoxynil/MCPA	0.30 + 0.56	23 b	22 bc	43 ab
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	7 c-d	17 b-d	13 c
Clethodim + MCPA	0.08 + 0.23	0 e	0 e	0 c
Clethodim + clopyralid	0.045 + 0.56	0 e	0 e	0 c
Clethodim + bromoxynil/MCPA	0.08 + 0.13	18 bc	20 bc	32 b
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.04/0.015 + 0.23	10 b-e	3 de	3 c
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	0 e	0 e	0 c
Sethoxydim + MCPA	0.60 + 1.10	17 b-d	10 c-e	10 c
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	40 a	47 a	57 a
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	22 b	28 b	37 b
Clethodim + MCPA	0.16 + 0.46	0 e	0 e	3 c
Clethodim + clopyralid	0.09 + 1.12	0 e	0 e	3 c
Clethodim + bromoxynil/MCPA	0.16 + 0.26	43 a	43 a	53 a
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.16/0.03 + 0.46	18 bc	23 bc	43 ab

Table 3.4. (continued). Effect of post-emerge herbicide tank-mix combination treatments on plant visual phytotoxicity percentage means (7 DAT) on three fibre flax cultivars (1999).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	3 de	3 d-e	7 c

In a column, means followed by a common letter are not significantly different by Tukey's HSD (P<0.050).

Bartlett's test for homogeneity of variances: Phytotoxicity Chi-Square = 24.09**

Where: ** - significant at 1%

Ariane cultivar and 47 and 57 % by the sethoxydim + bromoxynil/MCPA 2X treatment rate in the Escalina and Belinka cultivars, respectively.

The hand-weeded weed-free check showed phytotoxicity ratings of 3, 7 and 7% for Ariane, Escalina and Belinka, respectively, in 1998 and no phytotoxicities observed for Ariane and Escalina and only 3% for Belinka, in 1999. Herbicidal drift is assumed to be the main cause for these symptoms. Sethoxydim + MCPA exhibited 0, 7 and 10% phytotoxicity for Ariane, Escalina and Belinka, respectively, at the 1X rate in 1998 and no phytotoxic effects in 1999. The 2X rate showed much higher phytotoxic scores with 12, 27 and 18% in 1998 and 17, 10 and 10% in 1999 for the three cultivars, respectively. Sethoxydim + bromoxynil/MCPA treatments at the 2X rate in 1998 resulted in high scores of 30 and 32% for Ariane and Escalina, respectively, while little effect was observed for Belinka in all treatments at the 1X rates. In 1999, all cultivars were affected at both the 1X and 2X rates where Belinka suffered the highest phytotoxicity with scores of 43 and 57% for the two rates, respectively. Sethoxydim + clopyralid/MCPA severely affected Belinka at the 2X rate in 1998 with a score of 52% while in 1999, it showed a lower score at 37% which was however, higher than the other two cultivars. At the 1X rate, this treatment showed little phytotoxicity. All treatments containing clethodim + MCPA or clethodim + clopyralid at both 1X and 2X rates in both years proved to have high crop safety. The clethodim + bromoxynil/MCPA treatment however, resulted in heavy burning at the 1X and 2X rates on Ariane in 1998 with scores of 15 and 25%, respectively. This treatment in 1999 resulted in phytotoxicity among all cultivars whereby, Belinka showed the highest scores with 32 and 53% for the 1X and 2X rates, respectively. In 1998, all treatments containing fluazifop-p-ethyl/fenoxaprop-p-butyl with either MCPA or bromoxynil/MCPA were found to produce phytotoxicities under 10% at both the 1X and 2X rates for all three cultivars. In 1999, the fluazifop-p-ethy/fenoxaprop-p-butyl + bromoxynil/MCPA resulted in phytotoxicities of 10% and under at the 1X rate and 18, 23 and 43% at the 2X rate for the three cultivars, respectively, while the fluazifop-p-ethyl/fenoxaprop-p-butyl +MCPA treatments were all under 10% at both the 1X and 2X treatment rates.

Branching

The variances of the branching percentages were heterogeneous thus, tabulated as separate years (Table 3.5). The 1998 branching percentages were transformed using the square root transformation since the data were in the 0 to 30% range. There was a statistical difference among cultivars ($P=0.005$) in 1998 and in 1999 ($P<0.001$). There was no significant interaction between the cultivars and the treatments used ($P>0.050$) in 1998 and 1999 thus, the data are tabulated as combined treatment means (Table 3.5). The mean cultivar branching scores were found to be greater in 1999 than 1998 partly due to the lower plant populations of that year and higher phytotoxicity observed. In 1998, Belinka had the highest mean cultivar branching score of 11% and was statistically different ($P=0.005$) from Ariane (8%) and Escalina (7%). In 1999, Belinka again gave the highest mean cultivar branching score (54%) and was statistically different ($P<0.001$) from Ariane (43%) and Escalina (50%).

The average plant population among all three cultivars was 32% of the 1998 population and is therefore assumed that the branching score of 1999 is an overestimated score due to the low plant population effect. In 1998, the weed-check had the lowest

Table 3.5. Effect of post-emerge tank-mix combination treatments on mean plant branching percentages (14 DAT) of three fibre flax cultivars.

Treatment	Rate (kg a.i./ha)	Year	
		1998	1999
Weed Free	-	7 ab	46 c-e
Weed Check	-	2 b	29 f
Sethoxydim + MCPA	0.30 + 0.55	9 ab	45 c-e
sethoxydim + bromoxynil/MCPA	0.30 + 0.56	8 ab	52 b-e
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	6 ab	57 a-c
Clethodim + MCPA	0.08 + 0.23	9 ab	41 ef
Clethodim + clopyralid	0.045 + 0.56	7 ab	44 c-e
Clethodim + bromoxynil/MCPA	0.08 + 0.13	9 ab	49 c-e
Fluazifop p ethyl/fenoxaprop p butyl + Bromoxynil/MCPA	0.04/0.015 + 0.23	6 ab	41 ef
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	10 ab	42 de
Sethoxydim + MCPA	0.60 + 1.10	16 a	55 a-c
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	16 a	64 ab
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	16 a	68 a
Clethodim + MCPA	0.16 + 0.46	7 ab	46 c-e
Clethodim + clopyralid	0.09 + 1.12	4 ab	41 ef
Clethodim + bromoxynil/MCPA	0.16 + 0.26	11 ab	54 b-d
Fluazifop p ethyl/fenoxaprop p butyl + Bromoxynil/MCPA	0.16/0.03 + 0.46	7 ab	51 c-e
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	7 ab	50 c-e

In a column, means followed by a common letter are significantly different by Tukey's (P<0.050).

Bartlett's test for homogeneity of variances: Branching Chi-Square = 4.84*

Where: * - significant at 5%

mean treatment branching score of 2% and sethoxydim + MCPA, sethoxydim + bromoxynil/MCPA and sethoxydim + clopyralid/MCPA all at the 2X rates resulted in the highest mean treatment branching scores of 16%. In 1999, the weed-check again resulted in the lowest mean treatment branching score at 29%, while the sethoxydim + clopyralid/MCPA 2X treatment rate resulted in the highest mean branching score at 68% and was comparable to the mean branching scores of the 2X treatment rates of sethoxydim + MCPA and sethoxydim + bromoxynil/MCPA.

The weed check treatment in 1998 gave the lowest branching score mean among the three cultivars at 2% while in 1999, the weed check mean branching score among the three cultivars was 29%. This indicates that the 1999 plant population effect resulted in a 27% over-estimation in plant branching scores among all treatment-cultivar means. Therefore, taking this over-estimation into account, the increased phytotoxicity effect in 1999 resulted in an average increased branching score among all treatments, treatment rates, and cultivars by 14% due to the climatic conditions of that year.

Plant Heights

Harvest plant height data for the two years of observation were tabulated in Tables 3.6 and 3.7. Average cultivar plant heights in 1999 were 12, 5, and 15% shorter than 1998 for Ariane, Escalina, and Belinka, respectively. The hot and dry growing conditions following treatment application as well as the low plant populations resulted in these shorter harvest plant heights.

Table 3.6: Effect of post-emerge herbicide tank-mix combination treatments on harvest plant heights (90 DAS) on three fibre flax cultivars (1998).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Weed Free	-	91 AB	78 c-e	86 ab
Weed Check	-	92 ab	85 a-c	87 ab
Sethoxydim + MCPA	0.30 + 0.55	89 ab	79 b-d	84 ab
Sethoxydim + bromoxynil/MCPA	0.30 + 0.56	88 ab	85 a-c	89 ab
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	89 ab	73 de	82 b
Clethodim + MCPA	0.08 + 0.23	88 ab	82 a-c	89 ab
Clethodim + clopyralid	0.045 + 0.56	86 ab	81 a-d	92 a
Clethodim + bromoxynil/MCPA	0.08 + 0.13	85 ab	85 a-c	88 ab
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.04/0.015 + 0.23	90 ab	88 a	85 ab
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	93 a	86 a-c	85 ab
Sethoxydim + MCPA	0.60 + 1.10	87 ab	81 a-d	82 b
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	83 c	70 e	86 ab
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	84 bc	66 f	72 c
Clethodim + MCPA	0.16 + 0.46	91 ab	84 a-c	89 ab
Clethodim + clopyralid	0.09 + 1.12	86 ab	82 a-c	87 ab
Clethodim + bromoxynil/MCPA	0.16 + 0.26	89 ab	83 a-c	82 bc
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.16/0.03 + 0.46	92 ab	87 ab	91 a

Table 3.6. (continued). Effect of post-emerge herbicide tank-mix combination treatments on harvest plant heights (90 DAS) on three fibre flax cultivars (1998).

Treatment	Rate (kg a.i./ha)	Cultivar		
		Ariane	Escalina	Belinka
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	85 ab	85 a-c	87 ab

In a column, means followed by a common letter are not significantly different by Tukey's HSD (P<0.050).

Bartlett's test for homogeneity of variances: Branching Chi-Square = 18.78**

Where: ** - significant at 1%

Table 3.7: Effect of post-emerge herbicide tank-mix combination treatments on harvest plant heights (90 DAS) on three fibre flax cultivars (1999).

Treatment	**Rate (kg a.i./ha)**	**Cultivar**		
		Ariane	Escalina	Belinka
Weed Free	-	79 a-c	78 a-d	75 ab
Weed Check	-	70 ab	81 a	78 a
Sethoxydim + MCPA	0.30 + 0.55	77 a-d	78 a-d	74 a-c
Sethoxydim + bromoxynil/MCPA	0.30 + 0.56	81 a	75 b-d	74 a-c
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	73 d	75 b-d	72 b-e
Clethodim + MCPA	0.08 + 0.23	79 a-c	78 a-d	74 a-c
Clethodim + clopyralid	0.045 + 0.56	79 ab	80 ab	75 ab
Clethodim + bromoxynil/MCPA	0.08 + 0.13	79 ab	79 a-c	72 b-e
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.04/0.015 + 0.23	80 a	81 a	75 ab
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	81 a	77 a-d	74 a-c
Sethoxydim + MCPA	0.60 + 1.10	75 b-d	76 a-d	71 b-e
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	72 d	74 cd	69 c-e
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	74 cd	73 d	68 e
Clethodim + MCPA	0.16 + 0.46	80 ab	78 a-d	73 a-d
Clethodim + clopyralid	0.09 + 1.12	78 a-c	74 cd	71 b-e
Clethodim + bromoxynil/MCPA	0.16 + 0.26	72 d	76 a-d	68 e
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.16/0.03 + 0.46	79 a-c	79 a-c	71 b-e

Table 3.7. (continued). Effect of post-emerge herbicide tank-mix combination treatments on harvest plant heights (90 DAS) on three fibre flax cultivars (1999).

Treatment	**Rate (kg a.i./ha)**	**Cultivar**		
		Ariane	**Escalina**	**Belinka**
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	79 a-c	80 ab	74 a-c

In a column, means followed by a common letter are not significantly different by Tukey's HSD ($P<0.050$).

Bartlett's test for homogeneity of variances: Branching Chi-Square = 18.78**

Where: ** - significant at 1%

In 1998, the mean harvest plant heights differed significantly between cultivars ($P<0.001$) and treatments ($P<0.001$) (Table 3.6). Ariane resulted in the highest mean harvest plant height at 88 cm but was comparable to Belinka at 86 cm while Escalina had the shortest mean harvest plant height at 81 cm. In the Ariane cultivar, fluazifop-pethyl/fenoxaprop-p-butyl + MCPA at the 1X rate resulted in the highest mean harvest plant height of 93 cm and was comparable statistically to all other treatments except for sethoxydim + bromoxynil at the 2X rate which resulted in the lowest mean harvest plant height at 83 cm. In the Escalina cultivar, fluazifop-p-ethyl/fenoxaprop-p-butyl + bromoxynil/MCPA resulted in the highest mean harvest plant height at 88 cm and sethoxydim + clopyralid/MCPA at the 2X rate resulted in the lowest mean harvest plant height at 66 cm. In the Belinka cultivar, clethodim + clopyralid at the 1X resulted in the highest mean harvest plant height at 92 cm and the sethoxydim + clopyralid/MCPA at the 2X rate again resulted in the lowest mean harvest plant height at 72 cm. All lowest mean harvest plant heights in the three cultivars were observed in the 2X treatment rates. Respecting the recommended treatment rates to 1X, would reduce the variability among most treatments in the three cultivars except for three treatments in Escalina and one treatment in Belinka, which were significantly different ($P<0.001$) to the highest mean plant height.

In 1999, the mean harvest plant heights differed significantly between cultivars ($P<0.001$) and treatments ($P<0.001$) (Table 3.7). Ariane and Escalina had the highest mean cultivar harvest plant height at 77 cm while Belinka was statistically different ($P<0.001$) at 73 cm. In the Ariane cultivar, sethoxydim + bromoxynil/MCPA at the 1X rate and fluazifop-p-ethyl/fenoxaprop-p-butyl + MCPA at the 1X rate both had the highest mean harvest plant height at 81 cm while sethoxydim + bromoxynil/MCPA at the 2X rate and clethodim + clopyralid at the 2X rate had the lowest mean harvest plant height at 72 cm. In the Escalina cultivar, the weed check and the fluazifop-p-ethyl/fenoxaprop-p-butyl + bromoxynil/MCPA at the 1X rate resulted in the highest mean harvest plant height at 81 cm, whereas sethoxydim + clopyralid/MCPA at the 2X rate resulted in the shortest at 73 cm. In Belinka cultivar, the weed check resulted in the highest mean harvest plant height at 78 cm and the sethoxydim + clopyralid/MCPA and clethodim + bromoxynil/MCPA at the 2X rates resulted in the lowest at 68 cm. There was greater variation among 1X treatment rates in 1999 than 1998. The 1X sethoxydim + clopyralid/MCPA resulted among the shortest mean harvest plant heights along with 1X sethoxydim + bromoxynil/MCPA in the Escalina and Belinka cultivars.

Harvest Weight

Wet weight readings were taken at harvest to determine the dry matter content of the flax at harvest. Mean dry matter contents for 1998 were 35%, 36%, and 32% for Ariane, Escalina and Belinka, respectively. In 1999, the drier growing season resulted in higher mean dry matter contents with 46%, 42%, and 40% for Ariane, Escalina, and Belinka, respectively.

The dry weight observation was taken as the true yield indicator. The data were found to be heterogeneous during the conduct of the study thus, presented as separate years (Table 3.8). The mean cultivar dry weights were found to be significantly different in 1998 ($P<0.050$) and in 1999 ($P<0.001$) and there was no interaction ($P>0.050$) between the cultivars and treatments in 1998 and 1999. Therefore, the data were presented as

Table 3.8. Effect of post-emerge herbicide tank-mix combination treatments on harvest dry weight means of three fibre flax cultivars.

Treatment	Rate (kg a.i./ha)	Year	
		1998	1999
Weed Free	-	805.6 a-c	600.4 a
Weed Check	-	617.2 bc	245.6 b
Sethoxydim + MCPA	0.30 + 0.55	869.2 a-c	693.6 a
Sethoxydim + bromoxynil/MCPA	0.30 + 0.56	952.8 a-c	752.4 a
Sethoxydim + clopyralid/MCPA	0.20 + 0.66	778.8 a-c	754.8 a
Clethodim + MCPA	0.08 + 0.23	895.6 a-c	638.8 a
Clethodim + clopyralid	0.045 + 0.56	1005.6 a	576.4 a
Clethodim + bromoxynil/MCPA	0.08 + 0.13	810.8 a-c	760.8 a
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.04/0.015 + 0.23	932.8 a-c	712.4 a
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.08/0.015 + 0.17	865.2 a-c	605.4 a
Sethoxydim + MCPA	0.60 + 1.10	831.2 a-c	803.2 a
Sethoxydim + bromoxynil/MCPA	0.60 + 1.12	879.2 a-c	795.6 a
Sethoxydim + clopyralid/MCPA	0.40 + 1.22	602.4 c	772.8 a
Clethodim + MCPA	0.16 + 0.46	914.8 a-c	774.4 a
Clethodim + clopyralid	0.09 + 1.12	967.6 ab	649.6 a
Clethodim + bromoxynil/MCPA	0.16 + 0.26	830.4 a-c	705.2 a
Fluazifop p ethyl/fenoxaprop p butyl + bromoxynil/MCPA	0.16/0.03 + 0.46	944.0 a-c	668.8 a
Fluazifop p ethyl/fenoxaprop p butyl + MCPA	0.16/0.03 + 0.34	840.8 a-c	663.6 a

In a column, means followed by a common letter are significantly different by Tukey's ($P<0.050$).

Bartlett's test for homogeneity of variances: Dry Weight Chi-Square = 12.53**

Where: ** - significant at 1%

combined treatment dry weight means for both years. In 1998, Ariane had the highest mean cultivar dry weight at 914.4 g/m^2 and Belinka had the lowest at 818.4 g/m^2 and both were statistically comparable to the Escalina (824.8 g/m^2) mean cultivar dry weight. The clethodim + clopyralid 1X treatment resulted in the highest mean treatment dry weight at 1000.5 g/m^2 while the sethoxydim + clopyralid/MCPA resulted in the lowest mean treatment dry weight at 602.4 g/m^2. In 1999, Belinka resulted in the highest mean cultivar dry weight at 772.8 g/m^2 and the Escalina had the lowest at 581.2 g/m^2 and neither was statistically similar ($P<0.001$) to Ariane (674.8 g/m^2). The sethoxydim + MCPA 2X treatment rate resulted in the highest mean treatment dry weight at 803.2 g/m^2 while the weed check resulted in the lowest mean treatment dry weight at 245.6 g/m^2.

The 1999 mean cultivar dry weights were found to be 26%, 30%, and 6% lower than in 1998 for Ariane, Escalina and Belinka, respectively. Therefore, it is noticed that Belinka, which had the lowest plant population and highest phytotoxicity, responded with the highest branching score in 1999 had still attained 94% of the 1998 dry weight. The Ariane and Escalina cultivars were however, less capable to compensate to final harvest dry weight as Belinka did.

4. Conclusion

The experiments were designed to assess the suitability for use of non-registered pre-plant incorporated (PPI) and pre-emerge (PRE) herbicides and registered post-emerge (POST) herbicide tank-mix treatments on fibre flax in Québec. The impact of the different treatments was correlated to the morphological effects of plant population, branching, phytotoxicity, harvest plant height and harvest dry yield. Results obtained from the non-registered herbicides used in this experiment should not be interpreted as recommnedations for use in fibre flax production in Québec.

PPI treatments at their respective treatment rates were found to be suitable for use in fibre flax production. Although, pendimethalin reduced plant populations at emergence which resulted in elevated branching scores, there were no significant differences in harvest plant height or final harvest dry yield as compared to the trifluralin and EPTC^{+} treatments. Even incorporation of these herbicides into the top 4 cm of the soil and shallow seeding of flax no deeper than 2.5 cm minimized their effects on the reduction of the expected flax plant populations.

PRE treatments of trifluralin, linuron, and the combination of these at their respective treatment rates were all found to be suitable for use in fibre flax. Effects of the sandy soil type and low organic matter content in the 1998 linuron treatments resulted in decreased plant population.

POST treated flax showed variable degrees of phytotoxic response to both the 1X and 2X treatment rates. Although treatments containing bromoxynil/MCPA generally caused greater phytotoxic effects in 1999 at both the 1X and 2X treatment rates, final dry yield was generally not affected. The climatic conditions after treatment application in 1999 magnified the phytotoxicity effects but did not have any effects on final dry yield.

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Appendix A: Soil textures of three main soil types at Macdonald site.

	Chicot	Bearbrook	St-Bernard
Type	Fine Sandy-Loam	Clay	Loam
Soil Group	Gray Brown Podzolic	Dark Gray Gleysolic	Brown Forest
% Sand	61	17	44
% Silt	27	36	35
% Clay	12	47	21
pH	5.8-6.2	5.6-6.4	6.7-7.4

Source: Lajoie 1960

Appendix B: Monthly Meteorological Summary 1998 and 1999. Ste-Anne de Bellevue, Québec. Lat. 45' 26N Long. 73' 56W.

	1998						1999					
	Mean Temp (^0C)	Normal (^0C)	Growing Degree Days	Normal	Rainfall (mm)	Normal (mm)	Mean Temp (^0C)	Normal (^0C)	Growing degree days Base 5^0	Normal	Rainfall (mm)	Normal (mm)
April	7.9	5.9	304.4	73.0	26.0	70.0	6.5	5.9	61.6	73.0	20.1	70.0
May	16.8	13.1	365.0	256.7	58.8	70.8	15.5	13.1	326.8	256.7	39.6	70.8
June	18.8	18.1	414.8	396.3	137.7	88.3	20.0	18.1	450.3	396.3	109.5	88.3
July	20.2	21.1	471.5	496.7	75.2	89.7	21.7	21.1	516.2	496.7	100.4	89.7
August	20.0	19.8	465.9	457.2	79.0	99.9	19.8	19.8	429.4	457.2	51.5	99.9
Total	-	-	2021.6	1679.9	376.7	418.7	-	-	1784.3	1679.9	321.1	418.7

Source: Environment Canada

Appendix C

Table 1: Analysis of Variance for PPI Plant Population 1998

SV	DF	SS	MS	F	P
Treatment (T)	10	377.212	37.721	12.448	<0.001
Residual	22	66.667	3.030		
Total	32	443.879			

Table 2: Analysis of Variance for PPI Plant Population 1999

SV	DF	SS	MS	F	P
Treatment	10	26.545	2.655	2.305	0.049
Residuals	22	25.333	1.152		
Total	32	51.879			

Table 3: Combined Analysis of Variance for PPI Branching

SV	DF	SS	MS	F	P
Treatment	10	934.848	93.485	5.609	<0.001
Residuals	22	366.667	16.667		
Total	32	1301.515			

Table 4: Combined Analysis of Variance for PPI Harvest Plant Height

SV	DF	SS	MS	F	P
Treatment	10	40.807	4.081	2.190	0.060
Residuals	22	41.000	1.864		
Total	32	81.807			

Table 5: Analysis of Variance for PPI Dry Weight 1998

SV	DF	SS	MS	F	P
Treatment	10	30970.909	3097.091	0.849	0.59
Residuals	22	80223.333	3646.515		
Total	32	111194.242			

Table 6: Analysis of Variance for PPI Dry Weight 1999

SV	DF	SS	MS	F	P
Treatment	10	63956.545	6395.655	9.361	<0.001
Residuals	22	15031.333	683.242		
Total	32	78987.879			

Appendix D

Table 1: Analysis of Variance for PRE Plant Population 1998

SV	DF	SS	MS	F	P
Treatment (T)	10	378.848	37.885	13.300	<0.001
Residual	22	62.667	2.848		
Total	32	441.515			

Table 2: Analysis of Variance for PRE Plant Population 1999

SV	DF	SS	MS	F	P
Treatment	10	46.061	4.606	6.909	<0.001
Residuals	22	14.667	0.667		
Total	32	60.727			

Table 3: Combined Analysis of Variance for PRE Branching

SV	DF	SS	MS	F	P
Treatment	10	1724.242	172.424	8.430	<0.001
Residuals	22	450.000	20.455		
Total	32	2174.242			

Table 4: Combined Analysis of Variance for PRE Harvest Plant Height

SV	DF	SS	MS	F	P
Treatment	10	390.970	39.097	31.516	<0.001
Residuals	22	27.292	1.241		
Total	32	418.261			

Table 5: Analysis of Variance for PRE Dry Weight 1998

SV	DF	SS	MS	F	P
Treatment	10	81881.879	8188.188	5.604	<0.001
Residuals	22	32144.667	1461.121		
Total	32	114026.545			

Table 6: Analysis of Variance for PRE Dry Weight 1999

SV	DF	SS	MS	F	P
Treatment	10	40298.303	4029.830	7.506	<0.001
Residuals	22	11810.667	536.848		
Total	32	52108.970			

Appendix E

Table 1: Analysis of Variance for POST Plant Population 1998

SV	DF	SS	MS	F	P
Cultivar (C)	2	262.540	131.270	35.049	<0.001
Treatment (T)	17	53.341	3.138	0.838	0.647
CxT	34	101.127	2.974	0.794	0.776
Residual	108	404.500	3.745		
Total	161	821.508	5.103		

Table 2: Analysis of Variance for POST Plant Population 1999

SV	DF	SS	MS	F	P
Cultivar (C)	2	16.485	8.242	8.489	<0.001
Treatment (T)	17	33.680	1.981	2.040	0.015
CxT	34	26.578	0.782	0.805	0.762
Residual	108	104.867	0.971		
Total	161	181.609	1.128		

Table 3: Analysis of Variance for POST Phytotoxicity 1998

SV	DF	SS	MS	F	P
Cultivar (C)	2	31.790	15.895	0.233	0.793
Treatment (T)	17	9984.568	587.328	8.611	<0.001
CxT	34	5579.321	164.098	2.406	<0.001
Residual	108	7366.667	68.210		
Total	161	22962.346	142.623		

Table 4: Analysis of Variance for POST Phytotoxicity 1999

SV	DF	SS	MS	F	P
Cultivar (C)	2	1111.420	555.710	21.693	<0.001
Treatment (T)	17	41425.309	2436.783	95.123	<0.001
CxT	34	2510.802	73.847	2.883	<0.001
Residual	108	2766.667	25.617		
Total	161	47814.198	296.983		

Table 5: Analysis of Variance for POST Branching 1998

SV	DF	SS	MS	F	P
Cultivar (C)	2	25.974	12.987	5.672	0.005
Treatment (T)	17	109.507	6.442	2.813	<0.001
CxT	34	65.911	1.939	0.847	0.705
Residual	108	247.306	2.290		
Total	161	448.698	2.787		

Table 6: Analysis of Variance for POST Branching 1999

SV	DF	SS	MS	F	P
Cultivar (C)	2	3159.259	1579.630	26.656	<0.001
Treatment (T)	17	12894.444	758.497	12.800	<0.001
CxT	34	2974.074	87.473	1.476	0.068
Residual	108	6400.000	59.259		
Total	161	25427.778	157.937		

Table 7: Analysis of Variance for POST Harvest Plant Height 1998

SV	DF	SS	MS	F	P
Cultivar (C)	2	218.221	109.111	81.075	<0.001
Treatment (T)	17	333.951	19.644	14.597	<0.001
CxT	34	180.001	5.294	3.934	<0.001
Residual	108	145.347	1.346		
Total	161	877.520	5.450		

Table 8: Analysis of Variance for POST Harvest Plant Height 1999

SV	DF	SS	MS	F	P
Cultivar (C)	2	124.411	62.206	122.327	<0.001
Treatment (T)	17	136.820	8.048	15.827	<0.001
CxT	34	35.149	1.034	2.033	0.003
Residual	108	54.920	0.509		
Total	161	351.300	2.182		

Table 9: Analysis of Variance for POST Harvest Dry Weight 1998

SV	DF	SS	MS	F	P
Cultivar (C)	2	19434.259	9717.130	3.477	0.034
Treatment (T)	17	110775.556	6516.209	2.332	0.005
CxT	34	55569.556	1634.398	0.585	0.962
Residual	108	301800.667	2794.451		
Total	161	487580.000	3028.447		

Table 10: Analysis of Variance for POST Harvest Dry Weight 1999

SV	DF	SS	MS	F	P
Cultivar (C)	2	61955.577	30977.789	18.474	<0.001
Treatment (T)	17	157206.642	9247.450	5.515	<0.001
CxT	34	67996.534	1999.898	1.193	0.245
Residual	108	181094.500	1676.801		
Total	161	468253.253	2908.405		