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EFFECTS OF RAPESEED OIL AS AN ADDITIVE WITH CERTAIN HERBICIDE TREATMENTS

by

©

Norman H. Warrington

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled

EFFECTS OF RAPESEED OIL
AS AN ADDITIVE WITH CERTAIN HERBICIDE TREATMENTS

submitted by Norman H. Warrington in partial fulfilment of the requirements for the degree of Master of Science in Weed Science and Crop Ecology.

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Supervisor

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Date 1975

Growth chamber and field experiments were concerned with effects of the combination of oil from rapeseed (*Brassica campestris* or *B. napus* L.) with certain herbicide treatments.

Of a number of emulsifiers tested to determine their suitability for emulsifying rapeseed oil in water, Triton X-363M was found to be the most useful. Its optimum concentration range for this purpose was 5 to 10% v/v of the added oil. The 5% concentration selected for use in all subsequent experiments did not adversely affect the growth of rapeseed test plants.

Four fractions of rapeseed oil tested during preliminary experiments were crude oil; refined oil; refined and bleached oil; and refined, bleached, and deodorized oil. Since none of these fractions of rapeseed oil at rates of from 5.62 l/ha to 11.23 l/ha had any effect on the growth of wild oats, rapeseed, wheat, common buckwheat, oats, barley, and faba beans, the cheaper crude fraction was used in succeeding experiments. Crude rapeseed oil, sprayed at rates as much as 112.33 l/ha, caused no damage on barley, wheat, faba beans, and rapeseed plants.

Microscopic examination of Tartary buckwheat leaves sprayed with 2,4-D amine with and without added rapeseed oil indicated that the addition of oil to the spray increased the wetting and spreading of the herbicide on the leaf. The cuticle layer under the oil droplets appeared to be softened or partially dissolved. Such activity of the oil in combination with certain herbicides presumably was responsible for the increases in their phytotoxicity in various growth chamber, greenhouse, and field experiments.

In the growth chamber and greenhouse the oil significantly increased the phytotoxicity of 2,4-D amine on Tartary buckwheat, MCPA amine on Tartary buckwheat and hemp nettle, and benazolin on cleavers. There was no adverse effect of these 2,4-D and MCPA sprays on wheat or of the benazolin treatment on rapeseed. Rapeseed oil added to chloroxuron greatly increased the phytotoxicity of the herbicide on green foxtail but also reduced the selectivity to such an extent that the crop, faba beans, was severely damaged. The oil tended to increase the phytotoxicity of barban on wild oats and of dalapon and TCA on green foxtail but decreased the effect of nitrofen (niclofen) on Tartary buckwheat.

In field experiments the addition of rapeseed oil significantly increased the phytotoxicity of 2,4-D amine on Tartary buckwheat in wheat, MCPA amine on Tartary buckwheat in oats, and benazolin on cleavers in rapeseed without injury to the respective crops. Oil added to barban for treatment of wild oats, and to dalapon and TCA for sprays on green foxtail had no appreciable effect on the phytotoxicity of these herbicides. Rapeseed oil added to nitrofen decreased the effect of this herbicide on Tartary buckwheat in rapeseed.

Based only on economic considerations the treatments in which rapeseed oil increased the effect of the herbicide appear not to be profitable but this viewpoint could change if herbicide prices continue to rise and if there are rapeseed surpluses which lower the price of oil.

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INTRODUCTION

Rapeseed is the most important oilseed crop produced in Canada and is Canada's third most valuable annual crop following wheat and barley. The rapeseed crop reached a record 5.3 million acres in Canada in 1971. This country has become the world's largest producer and exporter of rapeseed (Downey *et al.*, 1974).

Ancient civilizations in Asia and along the Mediterranean recorded the use of rapeseed oil for illumination as early as 2000 B.C. and later it was used in foods and as a cooking oil. Although the crop was grown in Europe in the 13th century, its use was not extensive until the development of steam power when it was found that rapeseed oil would cling to water- and steam-washed metal surfaces better than any other lubricant. Rapeseed was first grown commercially in western Canada in 1942 as a war measure to supply oil for lubrication of marine engines of the Allied navies (Downey *et al.*, 1974). Rapeseed oil now has many industrial uses. As well as a lubricant for marine engines, a general purpose grease has been developed in which rapeseed oil replaces castor oil. The oil is also used in conjunction with tallow as a lubricant for cold rolling steel and in the manufacture of soft soap used in sizing cloth. The erucic acid fraction has special industrial application such as the lubrication of jet engines, the manufacture of plastics, the making of erucic ethylene glycol polyester surface film to reduce evaporation in rice paddies, and as a floatation agent in potash mining (Downey, 1965). On the other hand only a very low amount, or absence, of erucic acid is a requirement for high quality edible rapeseed oil.

In Canada the first edible rapeseed oil was extracted in 1956-57. Since then the market has expanded rapidly. Cooperative research on various aspects of plant breeding, rapeseed processing and utilization has resulted in rapeseed oil becoming the most widely used edible oil in Canada. It now makes up 40% of all vegetable oils consumed as margarine, shortening, salad oil and cooking oil (Downey *et al.*, 1974).

For many years petroleum oils have been used to increase the weed control activity of certain herbicides. Recently certain vegetable oils such as linseed oil and sunflower oil have been used effectively for the same purpose (Nalewaja, 1968). With the addition of either petroleum or vegetable oils to certain herbicides it has been possible to achieve satisfactory weed control from smaller amounts of the herbicide than were required for equivalent control without the oil additive. An associated advantage resulting from reduction of the herbicide dosage could be reduction of chemical residues in the field. This prompts considerations of the possible effectiveness of rapeseed oil as a herbicide adjuvant. In view of the lack of information on this subject the object of the research described in this thesis was to evaluate the effects of inclusion of rapeseed oil with various commonly used herbicidal treatments.

LITERATURE REVIEW

History of Use of Oils in the Herbicide Field

There is a long history of the use of oils in weed control. The weed killing ability of petroleum oils has been known since the beginning of the petroleum industry although they did not become commercially significant for this purpose until the early 1940's (Hammond, 1967). The first uses of oils as herbicides were for total weed control in firebreaks, roadsides, fence rows, and ditch banks. Oil sprays were used instead of tillage for weed control in citrus orchards in the 1930's (Crafts and Reiber, 1952). In the late 1940's fuel oil was widely used by railways for right-of-way weed control (Hammond, 1967). When labour became scarce during World War II, oil sprays in the United States saved many thousands of acres of carrots (*Daucus carota* L.) that would have been lost if hand cultivation had been required to weed them. Diesel oil emulsions were used in the guayule crop (*Parthenium argentatum* Gray) (used in rubber manufacture) to allow maximum production and complete mechanization for this crop, which was considered crucial to war-time production (Crafts and Reiber, 1952).

There were problems and critical periods in the history of the use of oil in the herbicide field. Stove oil, if not used carefully, left an oily flavour in carrots; synthetic rubber reduced the need for guayule; and fuel oil prices rose to a level that almost prohibited their use for weed control. Thus the future of oil in the herbicide field was in doubt. Yet farmers needed oil sprays for irrigation systems infested with weeds and for fence lines harbouring insects and diseases (Crafts and Reiber, 1952). Research continued and soon led to the finding that safe and effective weed control in carrot crops could be achieved by use of refined oils of the Stoddard solvent type. Stoddard solvent is a straight-run petroleum naphtha fraction of low flammability containing principally aliphatic hydrocarbons. Such use was extended to celery (*Apium graveolens* L.), parsnips (*Pastinaca sativa* L.), parsley (*Petroselinum hortense* Hoffm.), and dill (*Anethum graveolens* L.) crops. Foresters, finding that conifer seedlings were tolerant to refined oils, sprayed forest tree nurseries for weed control. It was also found that a somewhat less toxic oil could be safely used on flax (*Linum usitatissimum* L.) and onions (*Allium cepa* L.) (Crafts and Reiber, 1952). Altogether then, the scope for use of oils as herbicides became quite extensive.

Many attempts were made during the 1940's and 1950's to relate the herbicidal activity of oils to their chemical composition. It was generally concluded that in petroleum fractions aromatic and olefine compounds were among the most phytotoxic, while aliphatics were comparatively safe on certain crops (Havis *et al.*, 1952) (Foden, 1972) (Van Overbeek and Blondeau, 1954).

With the introduction from France in 1938 of the use of the dinitro compounds for selective weed control (Ashton and Crafts, 1973) and knowledge of the selective herbicidal properties of (2,4-dichlorophenoxy)acetic acid (2,4-D) made available in 1944 as a result of the United States Military's biological warfare program and British investigations (Peterson, 1967) the age of selective herbicides arrived. These selective herbicides could be applied in much lower volumes of water than the amounts of oils used by themselves (Crafts and Reiber, 1952). Development of various emulsifiable concentrate formulations of 2,4-D and similar compounds largely replaced wholly oil sprays. Use of oils in herbicide application generally involves the addition of 0.5% to 10% by volume of emulsified oil to aqueous sprays of water-soluble herbicides or aqueous dispersions of wettable powders (Foden, 1972).

Recently, due to the high cost of selective herbicides, there has been an even greater interest in the addition of emulsifiable oils to herbicide sprays. The main use has been that of 2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine (atrazine)-oil sprays in the Corn Belt of the United States. Addition of 9.35 to 18.7 l/ha (1 to 2 US gal/A) of light mineral oil caused increased control of grassy weeds in corn (*Zea mays* L.) especially in the drier areas where pre-emergence action of atrazine has been erratic (Bandeen, 1969) (Schrader, 1970) (McGlamery, 1971). Vegetable oils as an alternative to petroleum oil additives have in some instances provided very satisfactory results (Nalewaja, 1974). Various vegetable oils used in this way have included: corn (*Zea mays* L.) oil, peanut (*Arachis hypogaea* L.) oil, soybean (*Glycine max* (L.) Merr.) oil, safflower (*Cathamus tinctorius* L.) oil (Coats and Foy, 1971), linseed (*Linum usitatissimum* L.) oil, and sunflower (*Helianthus annuus* L.) oil (Nalewaja, 1968). The present thesis deals with experiments involving rapeseed (*Brassica* spp.) oil (Warrington and Corns, 1973).

Petroleum Oil Additives to Herbicides

Various types of petroleum oil fractions have been used with herbicides with varying degrees of success. It was first shown by Ennis (1951) that the phytotoxicity of 2,4-D and (2,4,5-trichlorophenoxy)acetic acid (2,4,5-T) could be increased by emulsifying 5% of a non-phytotoxic oil or diesel oil into the spray fluid. Gertsch (1952) found that the addition of 10% oil increased the activity of 2,4-D amine and a 2,4-D ester against beans. Little additional work was done on oil additives until Anderson and Jones at the University of Guelph, Ontario (Anderson, 1963) investigated the concept of using highly refined oils as carriers for herbicides in post-emergence applications. Their initial work was done using atrazine with a highly refined paraffinic oil (Imperial Oil Esso 862) as a post-emergence spray on field corn (Anderson and Jones, 1964a, 1964b, 1964c). In 1966, Sunoco Superior Spray Oil 11E received principal attention as an oil additive. Results showed that this oil improved the performance of atrazine (Verstraete and Bandeen, 1966) and 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) (Brown and Frank, 1966) as a post-emergence foliar spray in corn. In 1965, an experimental use was approved by the Ontario Department of Agriculture recommending the use of oil "to increase the post-emergence activity of atrazine and to extend the period of application" (Degreef *et al.*, 1970).

In the United States application of non-phytotoxic (phytobland) oil with atrazine was tried in 1966-7 and was found to improve weed control in corn (Miller, 1967) (Ross and Williams, 1967) (Bandeen, 1969) (Schrader, 1970) and in sorghum (*Sorghum* spp.) (Wicks *et al.*, 1967, 1968). Following the success of atrazine plus oil, oils were tested with other herbicides. Aya and Ries (1968) found that the addition of 18.7 l/ha (2 US gal/A) of a non-toxic paraffinic mineral oil enhanced the herbicidal activity of 3-amino-*s*-triazole (amitrol) to quackgrass (*Agropyron repens* (L.) Beauv.). Dexter and Smith (1969) found that 9.35 l/ha (1 US gal/A) of Sun Oil 11E when added to the herbicides 5-amino-4-chloro-2-phenyl-3(2H)-pyridazinone (pyrazon) and methyl *m*-hydroxycarbanilate *m*-methylcarbanilate (phenmedipham) increased weed control in sugar beets (*Beta vulgaris* L.). Miller and Nalewaja (1970) (1973) also found that oil additives increased the effectiveness of phenmedipham for weed control in sugar beets. Barrentine and Warren (1970) found isoparaffinic oil enhanced activity of 3-*tert*-butyl-5-chloro-6-methyluracil (terbacil) and isopropyl *m*-chlorocarbanilate (chlorpropham) on giant foxtail (*Setaria faberii* Herrm.). Added oil also increased the response to 2-*sec*-butyl-4,6-dinitrophenol (dinoseb) (Burt and Warren, 1971).

Not all work with oil additives has shown beneficial effects from their mixture with other compounds. Although herbicidal oils are still used in cotton (*Gossypium hirsutum* L.) (Robinson, 1973) some work involving, for example, addition of phytobland oil to monosodium methanearsonate (MSMA), 1,1-dimethyl-3-(α,α,α-trifluoro-*m*-tolyl) urea (fluometuron), 3-(hexahydro-4,7-methanoindan-5-yl)-1,1-dimethylurea (norea), and disodium methanearsonate (DSMA) showed no significant effect of this combination on weed control in cotton (Hogue, 1974). There was also no effect of the addition of phytobland oil to 3',4'-dichloropropionanilide (propanil) for the control of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) in rice (*Oryza sativa* L.) (Smith, 1974).

On balance, however, herbicidal preparations including non-phytotoxic oils have been sufficiently useful to warrant various accepted recommendations for post-emergence applications in corn in Canada and the United States and in sorghum, sugar cane (*Saccharum officinarum* L.) and Florida turf in the United States (Degroef *et al.*, 1970).

Physiological Effects of Adding Oils to Herbicides

Before herbicides can penetrate into a plant the spray droplets containing the chemical must be retained on and come into close contact with the leaf surface. Oil-water emulsion carriers for herbicides can aid in this retention and leaf wetting. Irregular surface wax deposits exert a great influence on wetting and the contact angle between the droplet of emulsion and the leaf surface (Crafts and Foy, 1962). Added oil reduces surface tension of the droplet which allows for better wetting and spreading (Bandeen, 1969). Saunders and Lonnecker (1967) used time-lapse motion picture photography to show differences between droplets of water containing herbicide and droplets of oil-water emulsion containing herbicide. They found that the droplet of water containing a wettable powder herbicide spread very little, about twice the diameter of the drop before it touched the leaf, and that when the water evaporated it left a spot of herbicide covering only a small portion of the available leaf surface. The oil containing droplet spread rapidly to cover an area 10 to 20 times that produced by a water droplet of the same size. This rapid wetting action served to distribute the herbicide uniformly and to bond the toxicant to the leaf surface. It was also found that the oil mixture had the ability to move up the leaf against the pull of gravity, cross natural boundaries in the leaf such as the midrib, and to produce a strong capillary action in the interstices of the plant.

Oil also acts as a sticker in that it evaporates less rapidly than water and therefore maintains the herbicide for a longer period of time in a moist or soluble condition allowing greater uptake by the plant (Bandeen, 1969). Using a light mineral oil Saunders and Lonnecker (1967) found that the oil stayed on the surface of the plant for about 7 days. The oil film was maintained long enough to give good weed control but not so long that it suppressed crop growth functions or caused residue problems.

Oils added to herbicides can also increase the penetration of the herbicide into the foliage of the plant. Penetration of a herbicide into a leaf is greatly influenced by the plant cuticle. The plant cuticle is a layer on the plant surface formed by extrusion from the epidermis. It is continuous and not cellular and is composed of layers of cellulose, pectin, and cutin, the latter containing wax platelets embedded in it. There is usually a layer of hydrophobic surface wax with various ornamentation (Robertson and Kirkwood, 1969). There exists a gradient from low polarity at the exterior of the cuticle to relatively high polarity in the layers bordering the epidermal cell wall. Lipophilic waxes predominate toward the outside, the outer layers contain only wax and semilipoidal, semipolar cutin. Hydrophilic substances, cellulose and pectin are in predominance in the inner regions (Foy, 1964). This gradient of polarity is of importance in the penetration of herbicides. Foy (1964) has reviewed the theory that there are two absorption pathways: an aqueous (polar) route and a lipoidal (apolar) route. For aqueous solutions of herbicides entry is through cracks, punctures, or areas of leaves not completely covered with waxy lamellae, then follows a polar (aqueous) route presumably by the hydrated cutin and/or hydrophilic pectin and cellulose portion of the cuticle. If the waxy surface layer is thick and there are no punctures then aqueous solutions have difficulty in penetrating. For oils or herbicides in oil carriers, absorption takes place directly through the waxy portion of cuticle via an apolar (lipoid) route (Foy, 1964). The sticker effect of oil and retardation of evaporation that Bandeen (1969) mentioned would leave water for the hydrophilic part of the route into the plant once the oil had helped penetration through the lipophilic layers. It has been found by Foy (1964), Bandeen (1969), Caseley (1970), and McGlamery (1971) that oils soften or solubilize the cuticle and/or plasma membrane, displacing lipoid molecules and increasing permeability, thus enhancing herbicide uptake through the lipophilic pathway and enabling plants with cuticles that restrict herbicide entry in the aqueous phase to be controlled. Using ^{14}C-labelled atrazine Schrader (1970) found that the oil-water emulsion doubled penetration of atrazine per unit area of leaf surface of corn. Peacock (1970) also found that the penetration of ^{14}C-labelled atrazine and 3,6-dichloro-o-anisic acid (dicamba) through astomatous leaf surfaces of Tradescantia (*Tradescantia fluminesis* Vell.) was increased by the use of oil-water emulsions as compared to 0.1% surfactant solution. Using ^{14}C-labelled mineral oil, he found that the oil itself penetrated the leaves. Saunders and Lonnecker (1967) found that only 10% of the oil applied actually penetrated to the interior. They came to the conclusion that it was not the penetration of the oil that was important but its softening action on the cutin layer. The plasticized cutin then acts as a transfer medium which allows the herbicide to migrate in all directions within the plasticized layer.

Therefore, by the addition of oil to herbicide sprays, retention, leaf wetting, and penetration are increased and thus more of the applied herbicide finds its way to the site of action. This also presents the opportunity of using less of the herbicide and still getting the required weed control.

Requirements of a Non-Phytotoxic Oil

The phytotoxicity of oil is associated with increased aromatic contents and decreased unsulfonated residue values (Peacock, 1970). In Phytobland (non-phytotoxic) oils, sometimes called "superior" oil because of their use as dormant orchard sprays, the aromatic content is quite low. Purity of oils is expressed as a UR (unsulfonated residue) value. Phytobland oils have UR values higher than 90%. That is, there is 10% sulfonated residue or 10% aromatic compounds. Viscosity is expressed as Saybolt Seconds Universal (SSU), indicating the time for a given quantity of oil to pass through a funnel orifice test. The larger the number, the more viscous is the substance. Common viscosities for phytobland oils are 90 to 130 SSU (McClamery, 1971).

An example of a non-phytotoxic oil is Sunoco Superior Spray Oil 11E. This oil has a viscosity of 100 SSU and an unsulfonated residue over 90% (Degreef *et al.*, 1970).

Peacock and Dybing (1969) also found that distillation temperature, refractive index, molecular weight, and flash point were all associated in determining herbicidal enhancement for paraffinic oils. Saunders and Lonnecker (1967) stated that non-phytotoxic crop spray oils generally average around 25 carbon atoms per molecule.

The rapeseed oil used in the work reported in this thesis was composed of fatty acids of triglycerides that vary from 16 to 22 carbons (Western Canadian Seed Processors Ltd., 1973).

Surfactants or Emulsifiers for Making Oil-Water Emulsions

Phytobland oils are usually sprayed at the rate of 11.23 to 22.47 l/ha (1 to 2 Imp gal/A) with enough water to make up a 112.33 to 224.66 l/ha (10 to 20 Imp gal/A) spray mixture. It is necessary to add an emulsifier to allow thorough mixing of water and oil. The usual emulsifier content is 0.5% to 2% (McGlamery, 1971).

Some emulsifiers are added to the oil by the manufacturers. For example Superior Spray Oil 11E contains an emulsifier specifically designed to provide emulsification in water up to 1200 ppm hardness in cold water (5°C) (Degreef *et al.*, 1970). The emulsifier must be "tailor made" to the properties of the given oil. This combination must in turn be compatible with a wide variety of surfactants used as dispersing agents in wettable powder herbicides or used as emulsifying agents in emulsifiable concentrate formulations of herbicides if the final spray mixture is to give maximum performance (Saunders and Lonnecker, 1967).

Some of the emulsifiers that have been used with phytobland oils are X-77 from Collodial Products Corp. (Barrentine and Warren, 1970), Tronic from Fisons Ltd. (Addink and Nalewaja, 1972) and Triton X-207 from Rohm and Haas (Wicks *et al.*, 1968) (Aya and Ries, 1968). Triton

X-207 seems to be the most commonly used emulsifier for this purpose, especially for emulsifying vegetable oils (Nalewaja, 1968) (Miller and Nalewaja, 1970, 1973).

Coats and Foy (1974b) have studied the effects of emulsifier concentration in petroleum oils on the uptake of ^{14}C-labelled atrazine by corn. They found that there was no additional promotion of atrazine-^{14}C uptake from the use of emulsifier concentration above 2.0% in the oil of a 10% oil-in-water emulsion. They used a range from 0.5% to 8.0% emulsifier (v/v).

The emulsifiable oils used in many of these experiments contain up to 5% emulsifier v/v of the oil. Spray solutions containing 4.55 l (1 Imp gal) of oil in 45.46 l (10 Imp gal) of water will therefore contain 0.5% of a surfactant, a concentration which has been shown by Parr and Norman (1965) to have considerable effect both on spray retention and herbicidal activity. The use of herbicide-surfactant controls can help to define the true effect of oil addition. Accordingly in the research described in this thesis emulsifier-herbicide treatments were used which contained the same amount of emulsifier used in various oil-emulsifier-herbicide applications (Warrington and Corns, 1974).

Since Triton X-207 is no longer cleared by the U.S. Food and Drug Administration for agricultural use (Coats and Foy, 1974a) the emulsifier used in this study was Triton X-363M, another Rohm & Haas product which proved to be satisfactory for use in preparation of material for the various treatments.

Vegetable Oils as Alternatives to Petroleum Oil Additives

Since initial experimentation with oil-water emulsions with atrazine in the early 1960's, much research has involved the use of different oil additives. Nalewaja (1968) first asked the question: "could oils, such as linseed or sunflower oil, be potentially useful as crop oils with various herbicides?" He also stated that if an oil from an agricultural crop would prove superior to petroleum oil in achieving effective weed control with herbicides, the benefits to the farmer could be multiplied. By using an agricultural crop oil with herbicides, farmers might not only increase their weed control and crop yields, but also help utilize the agricultural surpluses. Recently vegetable oils from linseed, soybeans, safflower, cottonseed, and peanuts have been used as alternatives to petroleum oil additives (Nalewaja, 1974). With the anticipated shortages of our petroleum resources, use of a renewable oil resource is another reason for shifting to oils of crop origin.

In 1968, the first field experiments were conducted using sunflower and linseed oil with 2% Triton X-207 and a petroleum oil with 1% Triton X-207 emulsifier. Nalewaja (1968) reported that linseed and sunflower oil when added to atrazine were equal in effect to petroleum oil at 9.35 l/ha (1 US gal/A) but the linseed and sunflower oil used at 2.34 l/ha (1 US qt/A) tended to result in better weed control than the regular use of 9.35 l/ha (1 US gal/A). Moreover 2.34 l/ha (1 US qt/A) of the vegetable oils induced better weed control than 2.34 l/ha (1 US qt/A) of petroleum. The results of greenhouse experiments were variable but generally substantiated the field experiments. Nalewaja and [illegible] (1968) also found that 2.24 kg/ha (2 lb/A) of pyrazon plus 9.35 l/ha (1 US gal/A) of linseed oil gave as good weed control in sugar beets as 4.48 kg/ha (4 lb/A) of pyrazon plus 9.35 l/ha (1 US gal/A) of Sun Oil 11E. This was confirmed by Dexter and Smith (1969). Miller and Nalewaja (1970, 1973) found that 2.34 l/ha (1 US qt/A) of linseed oil as an additive to phenmedipham was more effective than 2.34 l/ha (1 US qt/A) or 9.35 l/ha (1 US gal/A) of petroleum oil in controlling foxtail (*Setaria* spp.) and better than either petroleum oil or sunflower oil additives in controlling redroot pigweed (*Amaranthus retroflexus* L.). Linseed oil at 9.35 l/ha (1 US gal/A) was less effective than sunflower or petroleum oil additives in controlling kochia (*Kochia scoparia* (L.) Schrad.). From the results of greenhouse and field studies they concluded that the weed control obtained from phenmedipham with oil additives was influenced by the weed species and type and volume of oil.

Coats and Foy (1971) conducted an experiment to determine if a given vegetable oil was a better penetrant aid for atrazine and 2,4-D in the species of its origin than oils derived from the seeds of other species. The crops and oils used were corn, peanut, soybean, and safflower. They found that no apparent specificity either synergistic or antagonistic, existed between the vegetable oils tested as penetrant aids for atrazine and the species of their origin. Soybean oil was the only oil that appeared to be a better penetrant aid for uptake of 2,4-D by soybean than corn, peanut, or safflower oil.

Mitich (1972) recorded the same post-emergence control of broadleaf and grass weeds with atrazine applied with 2.34 l/ha (1 US qt/A) of linseed oil as with 9.35 l/ha (1 US gal/A) of Sunoco Superior Spray Oil 11E. McGlamery and Slife (1973) found that the use of linseed oil increased the giant foxtail and velvetleaf

(Abutilon theophrasti Medic.) control with both atrazine and 2-chloro-4-(1-cyano-1-methylethylamino)-6-ethylamino-s-triazine (cyanazine). Stahlman and Messersmith (1973) using a linseed oil additive at 2.34 l/ha (1 US gal/A) with the dimethylamine salt formulation of 2,4-D increased control of redroot pigweed by 28% over 2,4-D alone. They also found that linseed oil additives reduced spray drift of the dimethylamine formulation by 23-42%. Warrington and Corns (1974) using rapeseed oil as an additive to the dimethylamine salt formulation of 2,4-D reduced numbers of Tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) plants by 90% compared with those remaining after treatment with 2,4-D alone.

Addink and Nalewaja (1972) studied the effect of additives on dicamba. Using leafy spurge (*Euphorbia esula* L.), they found the order of ^{14}C-dicamba absorption with additives: linseed oil and saponified linseed oil > petroleum oil and Tronic > diesel oil and X-77. Absorption of ^{14}C-dicamba was 40% more when applied with linseed oil than with diesel oil.

About 1970 Rahcher Products, Minneapolis first marketed a product called 'Bio-Veg', an emulsifiable biodegradable vegetable oil, to be used with water as a supplemental carrier to atrazine 80W herbicide. It was 94.5% linseed oil and 5.5% emulsifier (Bio-Veg, 1971). This product has been tested as an additive with other herbicides besides atrazine. Dexter (1972) using Bio-Veg at 2.34 l/ha (1 US qt/A) with various herbicides found that addition of the oil increased the control of prostrate pigweed (*Amaranthus graecizans* L.) and common lambsquarters (*Chenopodium album* L.) without influencing sugar beet stand or yield. Nalewaja (1972a) and (Nalewaja *et al.*, 1973) found that the addition of oil increased the phytotoxicity of cyanazine four times, that is, 2.24 kg/ha (2 lb/A) alone was equal to 0.56 kg/ha (0.5 lb/A) with an oil additive. Linseed oil (Bio-Veg) as an additive generally tended to increase the phytotoxicity of cyanazine more than petroleum oil. Nalewaja *et al.* (1974a) confirmed this with a different preparation of linseed oil. Nalewaja (1972b) found that oil additives generally increased redroot pigweed control with bentazon and that linseed oil (Bio-Veg) increased phytotoxicity of bentazon more than petroleum oil. Nalewaja *et al.* (1974b) confirmed this experiment also using a different preparation of linseed oil.

Oil from rapeseed was used in one experiment as an additive to atrazine in Puerto Rico (Almodovar-Vega and Liuicki, 1972). They were comparing paraffinic oils with oil from rape, groundnut, sunflower, linseed, safflower, cotton, soybean, and maize. The vegetable oil preparations consisted of one-eighth vegetable oil plus seven-eighths No. 11 paraffinic oil. Linseed and cottonseed oils at 4.68 l/ha (0.5 US gal/A) plus atrazine at 0.84 kg/ha (0.75 lb/A) effected 95-100% grass control. All other oils except soybean oil resulted in 85-94% control when applied with 0.84 kg/ha (0.75 lb/A) atrazine.

The foregoing literature review indicates that prior to the present work there has been scarcely any research involving rapeseed oil-water emulsion carrier for herbicides. Consideration of the favourable Western Canadian and Alberta conditions for the production of rapeseed and the potential benefits from a successful additional use of its oil with herbicides motivated the research reported in this thesis.

I. LABORATORY EXPERIMENTS

A. Materials and Methods

1. Comparison of various emulsifiers

1a. Emulsifiers with oil and water

Procedure I. Varying amounts of different surfactants and emulsifiers were tested for their ability to emulsify rapeseed oil at the rate of 5.62 l/ha (0.5 Imp gal/A) or 11.23 l/ha (1.0 Imp gal/A) in a total volume of 134.8 l/ha (12 Imp gal/A) made up with distilled water. The products included in these tests with rapeseed oil are listed in Table 1.

A total mixture of 50 ml (representing 134.8 l/ha) was formed by placing 2.1 ml (representing 5.62 l/ha) or 4.15 ml (representing 11.23 l/ha) of rapeseed oil plus 0.5 ml (1%) or 1.0 cc (2%) surfactant into a 95 ml test tube. Sufficient distilled water was added to bring the total volume up to 50 ml. The liquid surfactants were added by percent volume by volume (v/v) of the total and powdered surfactants by percent weight by volume (w/v) of the total. The mixture was shaken by hand for one minute. The test tube was stoppered and placed in a test tube rack. Observations were made on the apparent homogeneity and the stability of the emulsion relative to the differences in length of time before phase separation became conspicuous.

Procedure II. This procedure involved more intensive comparisons of certain of the apparently superior emulsifiers used in Procedure I. Emulsifier concentrations used were 2.5%, 5%, and 10% v/v of the oil. Soap was added w/v. The oil was used at 11.23 l/ha (1 Imp gal/A) in a 112.33 l/ha (10 Imp gal/A) total preparation. In all

Table 1. List of products tested in order to emulsify rapeseed oil in water

Product	Source
Atlox 209 Atlox 210 Atplus 411F Atplus 526 CD 161 Renex 25 Renex 35 Renex 36 Tween 20	Atlas Chemical Industries Canada, Ltd. Brantford, Ontario
Ivory Liquid Dish Detergent Ivory Snow Soap Powder	Proctor and Gamble Company of Canada, Ltd.
Lux Pure Soap	Lever Brothers, Toronto
Nu-Film P	Green Cross Products, Montreal
Sparkleen Laboratory Detergent	Fisher Scientific Co., Pittsburg
Sponto AL69-66	Witco Chemical Corporation, New York.
Triton B-1956	Chipman Chemicals Ltd., Montreal
Triton XA Triton X-114 Triton X-207 Triton X-363M	Rohm and Haas Company, Philadelphia
Wex	Conklin Company Inc., Shakopee, Minnesota

cases except with soap powder, in order to achieve maximum stability of the preparation, the emulsifier was mixed with the oil before water was added. A 50 ml mixture was made up in small plastic bottles (75ml) with screw caps. The bottles were placed on a shaker (React-R-Shaker) for one minute. The contents of the bottles were then poured into 50 ml graduated cylinders. Observations of foaming and stability of the emulsion were made over a half hour period. Comparisons were also made concerning the ease with which the separated oil could be re-emulsified by shaking. This experiment was replicated three times.

1b. Emulsifiers with oil, water, and herbicides

This experiment was conducted in the same manner as described in Procedure 1. Emulsifiers Triton X-207 and Triton X-363M were used at 5% v/v of oil which was at 11.23 l/ha in 134.8 l/ha total preparation. Herbicides used in proportions equivalent to half recommended field rates were:

4-chloro-2-butynyl *m*-chlorocarbanilate (barban) 0.18 kg/ha (2.5 oz/A)

dimethylamine salt of (2,4-dichlorophenoxy)acetic acid (2,4-D amine) 0.35 kg/ha (5 oz/A)

butoxyethanol ester of (2,4-dichlorophenoxy)acetic acid (2,4-D ester) 0.35 kg/ha (5 oz/A)

2,2-dichloropropionic acid (dalapon) 0.56 kg/ha (0.5 lb/A)

trichloroacetic acid (TCA) 0.56 kg/ha (0.5 lb/A)

In all cases the emulsifiers were added to the oil and the herbicides were added to water before the water and oil were emulsified. Observations were made on the stability of the oil-water emulsion relative to the differences in length of time before phase separation became conspicuous in preparations with and without added herbicide.

1a. Efficacy of various concentrations of the selected emulsifier Triton X-363M

This experiment was performed in a manner similar to that used in Procedure 1. Rapeseed oil was used at 11.23 l/ha in total mixtures of 67.2 l/ha (6 Imp gal/A) and 134.8 l/ha (12 Imp gal/A). Emulsifier concentrations were 1,2,3, ... up to 20% v/v of the oil.

Observations were made regarding the stability of the emulsion.

2. Microscopic examination of leaves treated with herbicide, oil, and emulsifier.

Tartary Buckwheat plants used as the test species were grown in the greenhouse for one month. They were then put under drier conditions for two days to help form a thicker cuticle. Plants were sprayed with 0.35 kg/ha (5 oz/A) of the dimethylamine salt formulation of 2,4-D in water, 2,4-D amine in water with Triton X-363M emulsifier added, or 2,4-D amine in a rapeseed oil-water emulsion carrier. Also some were sprayed with 0.35 kg/ha of the butoxyethanol ester of 2,4-D in water. Four hours after spraying, when epinasty had commenced, leaves of these plants were examined under a reflecting light microscope mounted with a camera. Plants were also observed 48 hours after spraying.

B. Results, Discussion, and Conclusions

1. Comparison of various emulsifiers.

1a. Emulsifiers with oil and water

Procedure 1. On the basis of the many trials involving observations made over periods of time varying from 10 minutes to

24 hours all except 4 surfactants were eliminated as being unsatisfactory for use in emulsifying rapeseed oil in water. Several of these products, however, are known to be effective for use in other types of preparations not requiring mixture of oil and emulsifier as the first step. The four surfactants selected for the comparisons by Procedure II were Ivory Snow Soap Powder, Atplus 526, Triton X-207 and Triton X-363M.

Procedure II. The results obtained using the foregoing four emulsifiers are shown in Table 2.

Soap powder was least satisfactory for several reasons. First there was the problem of mixing. The soap powder had to be mixed in water first before oil could be added. Unless the soap powder was fully dissolved the emulsion was poor. Second there was excessive foaming upon shaking. Third at the higher concentrations the soap caused the mixture to become very viscous.

Results from the other three emulsifiers were more satisfactory and similar to each other but had certain differences. Triton X-363M foamed most, although the foam died down rapidly, and Triton X-207 foamed least, almost not at all. Triton X-207 and Atplus 526 were the most effective at higher concentrations but Triton X-363M was best at the lower concentrations. Consequently Triton X-363M was selected for use in subsequent experiments because of its emulsifying abilities at low concentrations and because it was less viscous than the other two emulsifiers, thus making it easier to work with. Triton X-207 and Atplus 526 adhered to glassware much more than Triton X-363M. Oil containing any of these three emulsifiers was easily re-emulsified after separation had occurred.

Table 2. Effect of different concentrations of certain emulsifiers on the emulsion of rapeseed oil in water

Emulsifier Concentration	Emulsifier	Foam Rating 0-5 5 = excessive foaming	Time Until First Separation (minutes)	Phase Separation of the 50 ml mixture after 0.5 hours		
				Water(ml)	Emulsion(ml)	Oil(ml)
2.5% v/v of the oil	Soap Powder	5	<1	10	36	4
	Triton X-363M	2	5	1	48	1
	Triton X-207	0	5	3	45.5	1.5
	Atplus 526	1	5	2	46.5	1.5
5.0% v/v of the oil	Soap Powder	5	<1	16	31.5	2.5
	Triton X-363M	1	15	2	47	1
	Triton X-207	0	15	1	48	1
	Atplus 526	0	7	1	46.5	2.5
10% v/v of the oil	Soap Powder	5	<1	8	[illegible]	2.5
	Triton X-363M	2	<1	7.5	38	4.5
	Triton X-207	0	1	2	44	4
	Atplus 526	1	1	2	45	3

1b. Emulsifiers with oil, water, and herbicides

Results are summarized as follows:

Triton X-207 + oil	Time before phase separation became conspicuous (min.)
no herbicide	30
barban	5
2,4-D amine	5
2,4-D ester	5
dalapon	15
TCA	15

Triton X-363M + oil	Time before phase separation became conspicuous (min.)
no herbicide	30
barban	10
2,4-D amine	10
2,4-D ester	10
dalapon	5
TCA	10

The above results indicate that in general the herbicides used did not adversely affect the stability of the emulsion formed, using Triton X-363M as much as they did when Triton X-207 was the emulsifier.

1c. Efficacy of various concentrations of the selected emulsifier Triton X-363M

There was no difference between the results from use of 11.23 l/ha rapeseed oil in 67.2 l/ha total volume compared with 134.8 l/ha total preparation with regard to the stability of the emulsion. There was a gradual increase in stability of the emulsion up to 5% v/v of the oil then it levelled off. There was little difference between 5% and 10% but over 10% the emulsion was unstable and the oil separated out in only a short time. Thus there was an optimum range of emulsifier concentration between 5 and 10%. Any concentration less than 5% or greater than 10% did not produce as stable an emulsion. It was concluded that 5% was the lowest concentration of emulsifier that would give the greatest stability of emulsion. Thus Triton X-363M emulsifier was used at 5% v/v of the oil in the remaining studies.

2. Microscopic examination of leaves treated with herbicide, oil, and emulsifier.

After four hours no droplets of water could be detected o[illegible]s sprayed with 2,4-D amine in water or in water containing em[illegible]r with 2,4-D ester in water. There were no visible dif[illegible] between leaves sprayed with any of these treatments and a con[illegible] leaf even under 220X magnification (Figs. 1, 2, 3, and 4). Under [illegible] magnification oil droplets from the 2,4-D amine sprayed in [illegible]ed oil-water emulsion carrier were clearly visible. The drople[illegible] had spread to cover large areas of the leaf surface (Fig. 5). This wetting and spreading action of the oil probably serves to distribute the herbicide more uniformly. On leaves sprayed 48 hours previously, oil droplets were still visible. The oil seemed to have bonded the herbicide to the leaf surface. It can probably be assumed that there is less evaporation of herbicide from the oil-water emulsion than that sprayed in a water carrier. Therefore the herbicide would be maintained for a longer period of time allowi[illegible] for greater uptake by the leaf.

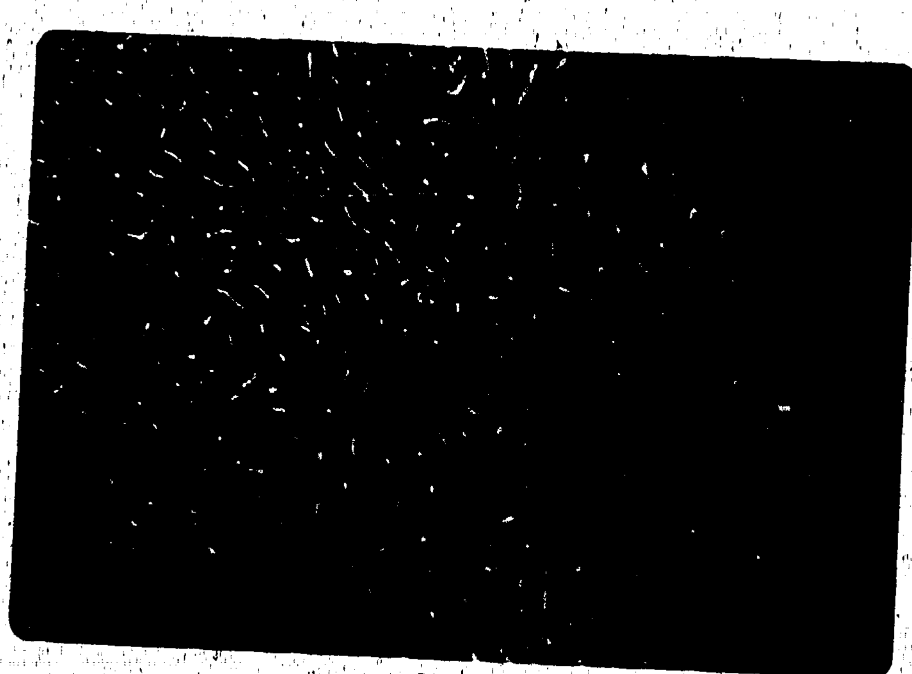

Figure 1. Tartary buckwheat leaf observed under reflecting light microscope at 65X magnification. (No treatment).

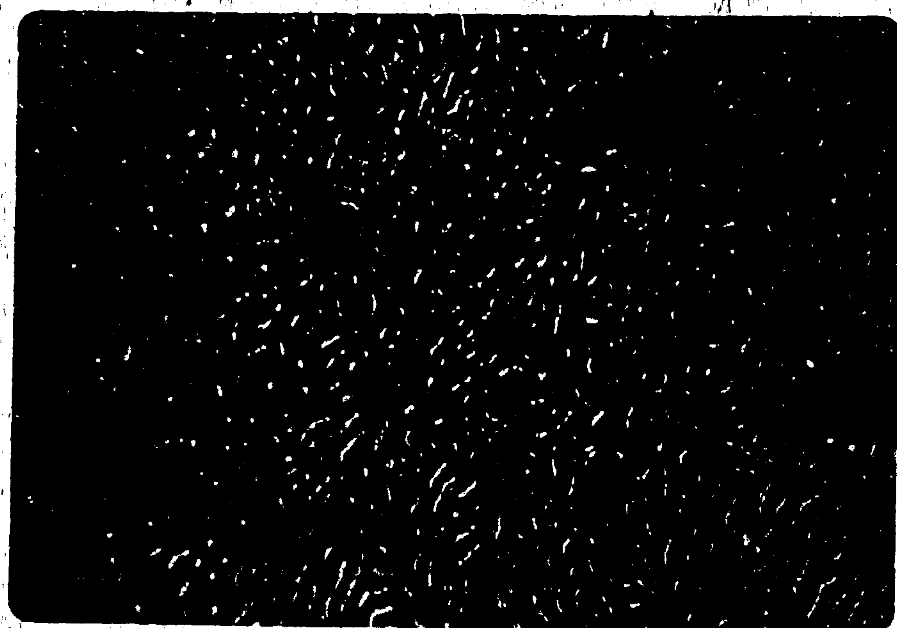

Figure 2. Tartary buckwheat leaf 4 hours after spraying with 2,4-D amine in water. (65X). Note absence of water droplets.

Figure 3. Tartary buckwheat leaf 4 hours after spraying with 2,4-D amine plus emulsifier in water. (65X). Note absence of water droplets.

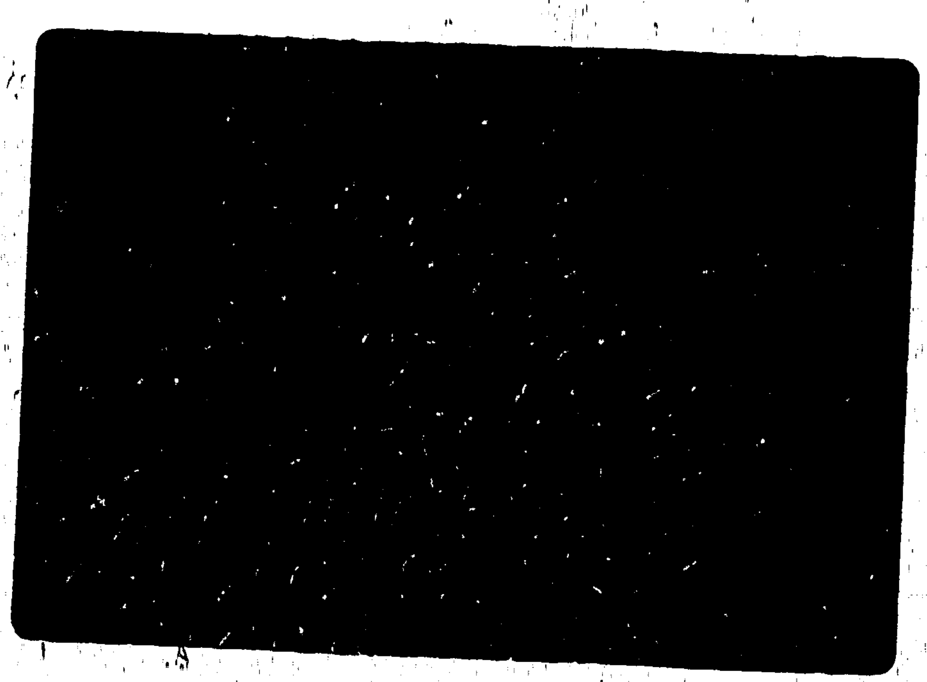

Figure 4. Tartary buckwheat leaf 4 hours after spraying with 2,4-D ester in water. (65X). Note absence of water droplets.

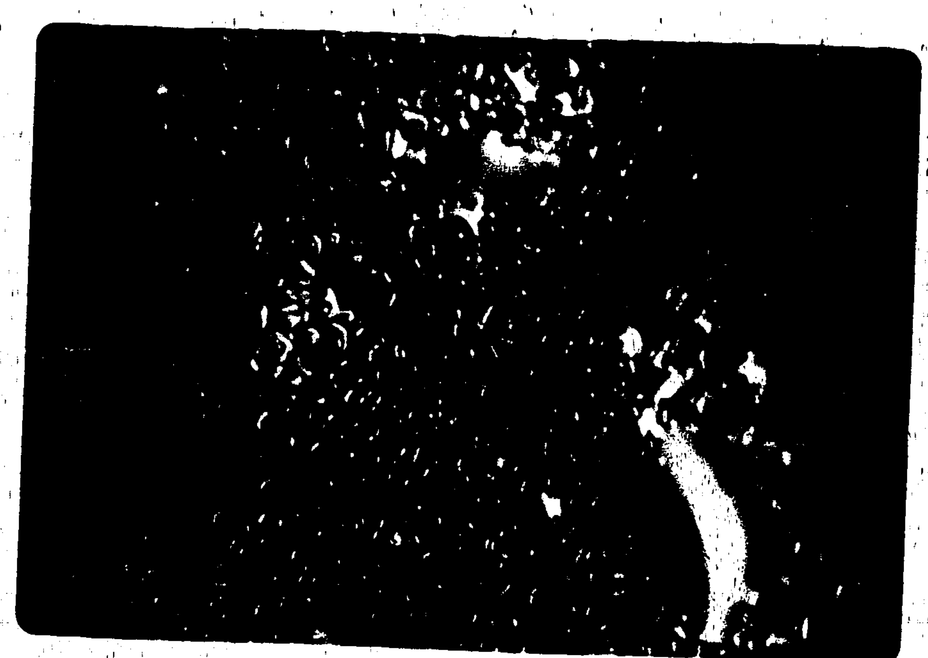

Figure 5. Tartary buckwheat leaf 4 hours after spraying with 2,4-D amine in oil-water emulsion carrier. (65X). Note presence of oil droplets which have spread to cover large areas of the leaf surface.

Similar results were found by Saunders and Lonnecker (1969) using a light mineral oil. With the aid of time-lapse motion picture photography, they found that the spray droplet containing oil had spread rapidly to cover an area 10 to 20 times that produced by a water droplet of the same size. They also found that the oil stayed on the surface of the plant for about seven days. The herbicide containing oil film remained long enough to give good weed control but not so long that it suppressed crop growth.

Also in the present study it could be seen from the microscopic examination, at 110X and 220X magnification that the oil had dissolved or solubilized part of the cuticle layer of the leaf. The waxy cuticular ridges were flattened and a relatively flat area was visible under the oil droplet (Fig. 6). This solubilizing action of oil on plant cuticle has also been reported by Foy (1964), Bandeen (1969), Caseley (1970), and McGlamery (1971).

In summary, the rapeseed oil-water emulsion carrier aided in wetting and spreading of the herbicide on the leaves and it seems safe to conclude that the dissolving or softening of the cuticle increased penetration of the herbicide.

Figure 6. Tartary buckwheat leaf 2 days after spraying with 2,4-D amine in oil-water emulsion carrier. (220X). Note area where cuticular ridges are flattened by the dissolving or softening action of the oil.

II. GROWTH CHAMBER AND GREENHOUSE EXPERIMENTS

A. Materials and Methods

1. General procedures.

General procedures applicable to the ensuing series of growth chamber and greenhouse experiments conducted during 1973 and 1974 were as follows. Any exceptions will be noted in the materials and methods for the individual experiments. Plastic pots 15 cm (6 in) in diameter were filled with 3:2:1 (loam:peat: sand) soil mixture to within 3 cm of the top. Depressions for seeds were made to a depth of 1 cm. The seeds were placed in the depressions and covered with about 1.5 cm of fine soil. Sufficient numbers were used to permit early thinning of seedlings in order to have the same number per pot. The pots were then placed in the growth chamber or the greenhouse.

Most of the experiments were performed in a growth chamber with temperature between 13°C (55°F) and 21°C (70°F), humidity between 45% and 60%, light intensity 24748 - 25824 lux (2300 - 2400 footcandles) and light duration of 16 hours (7 a.m. - 11 p.m.) daily. The pots were watered once a day and a liquid fertilizer (15-30-15) added once a month.

The greenhouse experiments were performed with a temperature of about 19°C (65°F), light intensity between 10670 - 17072 lux (1000 - 1600 footcandles) and light duration of 14 hours (8 a.m. - 10 p.m.) daily. The pots were watered twice daily and a liquid fertilizer (20-20-20) was added once a week.

Sprays were applied from a bottle attached to a sprayer head and an aerosol bomb type container. When the plants were sprayed, the pots for each treatment were placed in an area 0.37 m^2 (4 ft^2), outside the growth chamber. Watering was withheld for at least 16 hours after spraying. In most experiments observations were made every week until harvest time. Harvest data consisted of plant dry weight of top growth per pot as well as average plant height. In some cases a plant or culm count was made. Such counts are recorded in the relevant tabulation of results.

2. Tolerance of rapeseed to emulsifiers.

In this experiment Triton X-207 and Triton X-363M emulsifiers were used at the rate of 0.4% v/v in a 134.8 l/ha (12 Imp gal/A) mixture. The amount of emulsifier was proportional to that necessary to emulsify 11.23 l/ha (1 Imp gal/A) of rapeseed oil. On March 20, rape seeds (*Brassica campestris* (L.) var. Span) were planted following the general procedure. Rapeseed plants were sprayed on April 3 when they were in the 2-3 leaf stage. Treatments were replicated 3 times. Plants were harvested on April 24.

3. Comparison of effects of different fractions of rapeseed oil on wild oats and various crop species.

In this experiment four fractions of rapeseed oil supplied by Western Canadian Seed Processors Ltd., Lethbridge, (now Canbra Foods Ltd.), were used. The properties of these oils are summarized in Table 3.

3a. Wild oats and rapeseed

Two experiments using wild oats (*Avena fatua* L.) and Span rapeseed were performed. One had soap powder as the emulsifier at a rate of 0.5% w/v of the total mixture and the other involved Triton X-363M at 5% v/v of the oil. The oils were sprayed

Table 3. Standards for rapeseed oil fractions as found in Rapeseed Oil Specifications, Canadian Government Specification Board, September, 1972

Refinement	Differences: Free Fatty Acid (as Oleic Acid)	Moisture & Impurities	Colour
Crude	1.0% max.	0.5% max.	Green colour - Lighter than Standard A
Alkali Refined	0.05% max.	0.3% max.	7.0 Red, 70 Yellow max.
Refined and Bleached	0.05% max.	0.3% max.	3.5 Red, 35 Yellow max.
Refined, Bleached, Deodorized (with anti-oxidant added)	0.03% max.	Nil	1.0 Red, 10 Yellow max.

at 5.62 l/ha (0.5 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A) in a total preparation of 134.8 l/ha (12 Imp gal/A).

3a-1. The first experiment, in which soap powder was used as the emulsifier, was planted on February 6 following the general procedure. On February 19 the pots were sprayed when the rapeseed plants were in the 2-3 leaf stage 7.8 cm (3 in.) tall. The wild oats were in the 2-leaf stage 19 cm (7.5 in.) tall. Plants were harvested on March 9.

3a-2. The experiment using Triton X-363M as the emulsifier was planted on March 22 and sprayed on April 4 when both rapeseed and wild oats were in the 2-leaf stage. Plants were harvested on May 2.

3b. Wheat, common buckwheat, oats, rapeseed, barley, and faba beans

This experiment included wheat (*Triticum vulgare*, Vill.), common buckwheat (*Fagopyrum esculentum*, Moench), oats (*Avena sativa*, L.), rapeseed, barley (*Hordeum vulgare*, L.), and faba beans (*Vicia faba*, L.) as the test species. Triton X-363M was the emulsifier and only the 11.23 l/ha rate of the various fractions of oil was used. Treatments were replicated 4 times.

Thatcher wheat, Tokyo buckwheat, and Rodney oats were planted on January 29. The wheat and oats were thinned to 10 plants per pot and the buckwheat to 5 plants per pot on February 18. Plants were sprayed on February 19. The buckwheat was in the 2-3 leaf stage and the oats and wheat were both in the 4-leaf stage. Plants were harvested on March 29. The number of culms of wheat and oats per pot were recorded as well as the dry weight and height.

Only the height was recorded for the common buckwheat as the plants were suffering from a disease.

Span rapeseed, Conquest barley, and Diana faba beans were planted on April 5. The rapeseed and barley were thinned to 16 plants per pot and faba beans to 5 plants per pot. Plants were sprayed on April 23. The rapeseed was in the 3-5 leaf stage, the faba beans in the 2-4 leaf stage. Plants were harvested on July 8. No data became available for rapeseed because on June 5 it had to be discarded as a result of an infestation of aphids.

4. Extended comparisons of effects of crude rapeseed oil on barley, wheat, faba bean, and rapeseed plants.

Conquest barley, Thatcher wheat, Diana faba bean, and Span rape seeds were planted on April 5 following general procedures. Rapeseed, barley, and wheat were thinned to 16 plants per pot and faba beans to 5 plants per pot on April 10. Crude rapeseed oil was sprayed on April 23 at rates of 22.46 l/ha (2 Imp gal/A), and 56.16 l/ha (5 Imp gal/A) in a 112.33 l/ha (10 Imp gal/A) total mixture and 112.33 l/ha (10 Imp gal/A) of rapeseed oil in a 280.82 l/ha (25 Imp gal/A) total mixture. In all cases emulsifier Triton X-363M was used at 5% v/v of the oil. All treatments were replicated 4 times. Wheat plants were sulphur dusted on April 30 to control an infection of powdery mildew (*Erysiphe graminis* var. *tritici*) which occurred after the oil treatments. Rapeseed was harvested on June 5, faba beans on June 27, barley and wheat on July 8.

5. Herbicide treatments with and without rapeseed oil additive.

5a. <u>2,4-D amine and 2,4-D ester on Thatcher wheat and Tartary buckwheat</u>

Two experiments were performed using 2,4-D amine and 2,4-D ester. One had soap powder as the emulsifier at a rate of 0.5% w/v of the total mixture and the other had Triton X-363M at 5% v/v of the oil. Thatcher wheat and Tartary buckwheat plants were sprayed in the 2-3 leaf stage with the dimethylamine salt of 2,4-D at 0.35 kg/ha (5 oz/A) with and without rapeseed oil and with 0.17 kg/ha (2.5 oz/A) of the butoxyethanol ester of 2,4-D. The rapeseed oil was added at a rate of 11.23 l/ha in a 134.8 l/ha total preparation. Treatments were replicated 3 times. The number of surviving Tartary buckwheat plants was recorded at harvest time.

5a-1. The first experiment in which soap powder was used as the emulsifier was planted on February 22 and sprayed on March 8. Plants were harvested on April 6.

5a-2. The experiment using Triton X-363M as the emulsifier was planted on May 2 and sprayed on May 22. Plants were harvested on July 16.

5b. <u>2,4-D amine on Tartary buckwheat</u>

Tartary buckwheat was planted October 18 and was thinned to 15 plants per pot on October 29. Plants were sprayed on November 8 at the 2-3 leaf stage with 0.28 kg/ha (4 oz/A) of 2,4-D amine. Rapeseed oil was added at 2.81 l/ha (0.25 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A) in a 134.8 l/ha total preparation. Treatments were replicated 5 times in a Latin square design experiment. Tartary buckwheat was harvested on November 27.

5c. <u>Barban on wheat, rapeseed, and wild oats</u>

A series of three experiments was established to determine the effect of rapeseed oil added to 4-chloro-2-butynyl *m*-

chloro[illegible] (barban) sprays on wheat, rapeseed, and wild oats. [illegible]rban [illegible]ed at 0.17 kg/ha (2.5 oz/A) with and without added [illegible]seed [illegible]t 11.23 l/ha (1 Imp gal/A) in a total preparation of 1[illegible]8 l/[illegible] (12 Imp gal/A). Treatments were replicated 3 times in the fir[illegible] 2 [illegible]periments and 5 times in the last experiment.

5c-1. In the first experiment using soap powder as the emuls[illegible]er Thatcher wheat, Span rapeseed, and wild oats were planted on Feb[illegible]ry 6. Pots were thinned to 20 plants on February 15. On Februar[illegible]9 wheat in the 3-leaf stage, rapeseed in the 2-3 leaf stage, and wild [illegible]ats in the 2-leaf stage were sprayed with barban. Plants were harvested on March 28.

5[illegible]2. In the second experiment using Triton X-363M as the emulsifie[illegible] and wild oats were planted March 16. Both species were in the 2-leaf stage when sprayed on March 27. Plants were harvested on May 3. The number of surviving culms per pot was recorded.

5c-3. In another experiment using Triton X-363M emulsifier wild oats were planted on November 20. On December 2, wild oat plants were sprayed at 2 leaf stage with barban 0.17 kg/ha with rapeseed oil added at rates of 2.81 l/ha (0.25 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A) in a 134.8 l/ha total preparation. Treatments were replicated 5 times in a Latin square design experiment. Plants were harvested on February 3 when heads had appeared in the control treatment. The number of surviving wild oat plants per pot was recorded.

5d. <u>Dalapon and TCA on green foxtail, rapeseed, and barley</u>

A series of four experiments was established to determine the effects of 2,2-dichloropropionic acid (dalapon) and trichloroacetic acid (TCA) with added rapeseed oil on green foxtail (*Setaria viridis* (L.) Beauv.), rapeseed, and barley.

In the first two experiments the same rates of dalapon, 0.56 kg/ha (0.5 lb/A), and TCA, 0.56 kg/ha, were used with and without added rapeseed oil at 11.23 l/ha (1.0 Imp gal/A) in a total preparation of 134.8 l/ha. Treatments were replicated 3 times. The crop species used were rapeseed and barley. It is well known that TCA is recommended for use in rapeseed and barley but dalapon is only recommended for use in rapeseed. However, dalapon was also used on barley in these experiments to determine if there would be any additional effect with rapeseed oil added to dalapon.

5d-1. In one experiment, using soap powder as the emulsifier, Span rapeseed, Husky barley, and green foxtail were planted on March 1. Plants were sprayed on March 12 when all species were in the 2-3 leaf stage. The plants were harvested on April 10.

5d-2. In the second experiment, using Triton X-363M as the emulsifier, the same species were planted on April 13. Plants were sprayed on April 25 when all species were in the 2-3 leaf stage. The plants were harvested on June 1.

5d-3. In the next experiment only green foxtail and Conquest barley were planted on June 7. Plants were sprayed with dalapon at 0.74 kg/ha (0.66 lb/A) and TCA at 1.12 kg/ha with and without rapeseed oil at 11.23 l/ha when both species were in the 2-leaf stage on June 18. The rate of dalapon was increased to 0.74 kg/ha to determine if there could be complete kill of green foxtail when oil was added. The rate of TCA was increased to 1.12 kg/ha because the lower rate did not effect very good control of the green foxtail. Triton X-363M was used as the emulsifier. Treatments were replicated 6 times on the green foxtail but only 3 times on the barley. Plants were harvested on August 2.

5d-4. The fourth experiment was planted on October 16 using only green foxtail. Plants were sprayed on October 29 in the 2-3 leaf stage about 5 cm tall. The rate of dalapon used was 0.45 kg/ha (0.4 lb/A) and the rate of TCA 1.4 kg/ha (1.25 lb/A). Rapeseed oil was added to dalapon at 2.81 l/ha (0.25 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A) and to TCA at 11.23 l/ha. Treatments were replicated 4 times. Plants were harvested on November 19.

5e. <u>MCPA amine on Tartary buckwheat, wheat, and hemp nettle</u>

A series of four experiments was established to study the effect of rapeseed oil added to the dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid (MCPA amine) on Tartary buckwheat, wheat, and hemp nettle (*Galeopsis tetrahit* L.). Hemp nettle seeds were soaked in a solution of 500 ppm of gibberellic acid for 22-24 hours before planting.

5e-1. In the first experiment Tartary buckwheat and Thatcher wheat were planted on October 30. Plants were sprayed on November 20 with 0.35 kg/ha (5 oz/A) of MCPA amine with and without added rapeseed oil when both species were in the 3-4 leaf stage. Another treatment added for comparison was 0.35 kg/ha of MCPA plus 0.14 kg/ha (2 oz/A) of 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron). This is proportional to the recommended field treatment. Treatments were replicated 4 times. Plants were harvested on January 7.

5e-2. In the second experiment Tartary buckwheat, wheat, and hemp nettle were planted on December 21. Plants were sprayed on January 7 with 0.42 kg/ha (6 oz/A) of MCPA amine with and without added rapeseed oil when the wheat was in the 3-leaf stage, the Tartary buckwheat in the 3-4 leaf stage and the hemp nettle in the 2-leaf stage. A treatment of 0.42 kg/ha of MCPA amine plus 0.14 kg/ha of linuron was used for comparison. Treatments were replicated 4 times. Hemp nettle was harvested February 1, Tartary buckwheat on February 25, and wheat on June 5. The number of heads per pot, number of seeds per pot, and seed weight per pot was recorded for the wheat.

5e-3. In the third experiment only hemp nettle was planted on April 10. Plants in the 6-leaf stage were sprayed on May 8 with 0.42 kg/ha (6 oz/A) of MCPA amine with and without added rapeseed oil. Treatments were replicated 4 times. Plants were harvested on June 5 when the control plants were beginning to flower.

5e-4. In the fourth experiment only hemp nettle was planted on November 15. Plants were sprayed on December 6 in the 2-4 leaf stage with 0.35 kg/ha (5 oz/A) of MCPA amine. Rapeseed oil was added at 2.81 l/ha (0.25 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A). Treatments were replicated 5 times in a Latin square design. The hemp nettle was harvested on January 6. The percentage of original plants killed was calculated.

5f. Chloroxuron on green foxtail and faba beans

Two experiments were established to study the effects of the addition of rapeseed oil to 3-[p-(p-chlorophenoxy)phenyl]-1,1-dimethylurea (chloroxuron) on green foxtail and faba beans.

51-1. In the first experiment green foxtail and Diana faba beans were planted on February 27. Green foxtail was thinned to 20 plants per pot and faba beans to 6 plants per pot. Plants were sprayed on March 13 with 1.12 kg/ha (1.0 lb/A) of chloroxuron with and without 11.23 l/ha of rapeseed oil. The green foxtail plants were in the 3-leaf stage and faba beans in the 2-3 trifoliate stage. Treatments were replicated 4 times. The plants were harvested on June 4. (greenhouse)

51-2. In the second experiment green foxtail and Diana faba beans were planted on June 27. Plants were sprayed on July 9 when green foxtail was in the 2-3 leaf stage and faba beans in the 2-trifoliate stage with chloroxuron at 0.84 kg/ha (0.75 lb/A) with and without rapeseed oil and chloroxuron at 0.56 kg/ha (0.50 lb/A) and 0.28 kg/ha (0.25 lb/A) with rapeseed oil at a rate of 11.23 l/ha. Treatments were replicated 4 times. Plants were harvested on August 14. (growth chamber)

58. Nitrofen on stinkweed and lamb's quarters

This experiment using 0.56 kg/ha (8 oz/A) of 2,4-dichlorophenyl *p*-nitrophenyl ether (nitrofen) with and without 11.23 l/ha (1.0 Imp gal/A) of rapeseed oil was established to attempt to confirm results obtained from field experiments with nitrofen. On June 28 stinkweed (*Thlaspi arvense* L.) and lamb's-quarters (*Chenopodium album* L.) were planted after being soaked for 16 hours in 500 ppm of gibberellic acid to promote their germination. Plants were sprayed on July 19 when stinkweeds were in the 2-4 leaf stage and lamb's-quarters in the 2-6 leaf stage. Treatments were replicated 4 times. Plants were harvested on July 31.

5h. Benazolin on cleavers and rapeseed

Two experiments were established to attempt to confirm results obtained in the field with 4-chloro-2-oxo-benzothiazoline-3-ylacetic acid (benazolin) with and without rapeseed oil on cleavers (*Galium aparine* L.) and rapeseed.

5h-1. In the first experiment cleavers and Span rapeseed were planted on August 8. Plants were sprayed on August 24 with 0.42 kg/ha (6 oz/A) of benazolin with and without rapeseed oil at 11.23 l/ha (1.0 Imp gal/A) and 0.84 kg/ha (12 oz/A) of benazolin when the cleavers were in the first whorl stage and rapeseed was in the 3-4 leaf stage. Treatments were replicated 4 times. The rapeseed and cleavers were harvested on September 26.

5h-2. In the second experiment cleavers and Span rapeseed were planted on November 14. Rapeseed was thinned to 16 plants per pot and cleavers to 17 plants per pot on November 22. Plants were sprayed on November 28 with 0.35 kg/ha (5 oz/A) of benazolin when the rapeseed was in the 3-4 leaf stage and cleavers in the 1-2 whorl stage. Rapeseed oil was added at 2.81 l/ha (0.25 Imp gal/A) and 11.23 l/ha (1.0 Imp gal/A). Treatments were replicated 5 times in a latin square design experiment. Plants were harvested on December 31. The numbers of surviving cleavers were recorded at harvest time.

B. Results, Discussion, and Conclusions

(Note: Topic 1, "General procedures", was completed under "Materials and Methods").

2. Tolerance of rapeseed to emulsifiers.

There was no apparent adverse effect of the emulsifiers on rapeseed plants. (Table 4).

Table 4. Effects of emulsifier sprayed on rapeseed plants. (Means of 3 replications).

Treatments	Average plant height (cm)	Dry weight per pot (g)
Control	72.0 a*	10.18 a
Triton X-207	71.3 a	10.66 a
Triton X-363M	75.3 a	10.47 a

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan, 1955).

3. Comparison of effects of different fractions of rapeseed oil on wild oats and various crop species.

3a. Wild oats and rapeseed

The results from the two experiments one using soap powder, 3a-1, and the other using Triton X-363M as emulsifier, 3a-2, were similar so only the data from the Triton X-363M experiment are presented here (Table 5).

There was no significant difference between any of the oil treatments and the control.

3b. Wheat, common buckwheat, oats, rapeseed, barley, and faba beans

There was no significant difference between any of the oil treatments and the control for any of the species. Data from March 29 and July 8 harvests are shown in Table 6.

From the three experiments, 3a-1, 3a-2, 3b, using the different fractions of rapeseed oil, it was concluded that none of the fractions had any toxic effects on any of the species tested. Also, as in Experiment 2, there was no phytotoxic effect of the emulsifier Triton X-363M alone on any of the test species.

It was concluded that because there were no differences among the fractions of rapeseed oil, the crude material being least expensive, would be the most logical for use in succeeding experiments.

4. Extended comparisons of effects of crude rapeseed oil on barley, wheat, faba bean, and rapeseed plants.

There was no significant difference between any of the rates of oil and the control at the 1% level using Duncan's Multiple Range Test (Table 7), but there was a significant difference at the 5%

Table 5. Effects of various fractions of rapeseed oil on wild oat and rapeseed plants. (Means of 3 replications).

Treatment	(l/ha)	Rapeseed Average height (cm)	Rapeseed Dry weight per pot (g)	Wild Oats Average height (cm)	Wild Oats Dry weight per pot (g)
Control		53.0 a*	3.39 a	66.3 a	3.65 a
Emulsifier[1]		49.3 a	2.67 a	67.0 a	5.06 a
Crude oil[2]	5.62	41.7 a	4.02 a	68.0 a	4.58 a
Crude oil	11.23	58.7 a	3.72 a	69.3 a	4.89 a
Refined oil	5.62	47.0 a	3.58 a	67.3 a	4.94 a
Refined oil	11.23	53.3 a	3.16 a	64.3 a	5.13 a
Refined & bleached oil	5.62	45.7 a	3.28 a	65.0 a	4.88 a
Refined & bleached oil	11.23	43.0 a	3.11 a	65.3 a	4.91 a
Refined, bleached & deodorized oil	5.62	49.0 a	3.10 a	66.3 a	4.79 a
Refined, bleached & deodorized oil	11.23	38.7 a	2.04 a	64.3 a	4.59 a

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan, 1955).

[1] Triton X-363M 0.5% v/v of total mixture.

[2] All oil treatments contain Triton X-363M emulsifier at 5% v/v of the oil.

Table 6. The effects of different fractions of rapeseed oil on various crop species. (Means of 4 replications).

	Wheat (average per pot)			Oats (average per pot)			Common Buckwheat	Barley (average per pot)			
	Height (cm)	No. of Culms	Weight (g)	Ht. (cm)	No. of Culms	Weight (g)	Height (cm)	Height (cm)	Weight (cm)	Height (g)	Weight (g)
Control	56.0a	38a	13.80a	59.5a	25a	18.30a	64.5a	70.0a	28.12a	92.5a	21.4a
Emulsifier	54.8a	39a	13.66a	63.5a	27a	17.55a	73.2a	58.8a	25.42a	81.2a	19.2a
Crude Oil	60.2a	37a	15.14a	55.2a	23a	18.40a	79.0a	62.5a	23.30a	83.8a	19.7a
Refined Oil	57.2a	42a	13.73a	62.2a	24a	16.95a	73.2a	58.8a	22.42a	81.2a	17.3a
Refined and Bleached	58.8a	39a	14.05a	60.0a	26a	16.50a	71.8a	66.8a	28.80a	82.5a	20.6a
Refined, Bleached and Deodorized	56.5a	42a	16.11a	61.8a	23a	17.65a	74.0a	61.2a	23.40a	93.0a	17.2a

*Means followed by the same letter are not significantly different at 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 7. Effects of different rates of crude rapeseed oil on barley, wheat, faba beans, and rapeseed plants. (Means of 4 replications).

	Rapeseed (per pot)		Faba Beans (per pot)		Wheat (per pot)		Barley (per pot)	
	Height (cm)	Weight (g)	Height (cm)	Weight (g)	Height (cm)	Weight (g)	Height (cm)	Weight (g)
Control	50.0	5.9a*	92.5	21.4a	85.0	19.3a	70.0	28.1a
22.46 l/ha oil	45.5	6.3a	76.2	21.6a	85.8	21.8a	74.8	34.4a
56.15 l/ha oil	51.0	6.0a	83.8	20.6a	81.2	18.4a	66.2	27.8a
112.33 l/ha oil	55.3	5.7a	77.5	19.1a	76.8	16.4a	71.8	30.4a

*Means followed by the same letter are not significantly different at 1% level using Duncan's Multiple Range Test (Duncan, 1955).

level in dry weight of wheat. The 112.33 l/ha rate of oil may have predisposed the wheat to the infection of powdery mildew. Other than this possible effect, there was no phytotoxicity of crude rapeseed oil applied in volume as great as 112.33 l/ha on the species tested.

5. Herbicide treatments with and without rapeseed oil additive.

5a. 2,4-D amine and 2,4-D ester on Thatcher wheat and Tartary buckwheat

The results from the two experiments, one using soap powder, 5a-1, and the other using Triton X-263M as emulsifier, 5a-2, were similar. There were no significant differences among any of the treatments using 2,4-D amine with and without rapeseed oil additive or among any of the treatments using 2,4-D ester with and without rapeseed oil additives. Control of Tartary buckwheat was in the range of 80-100%. The 2,4-D amine with added oil tended to give better control than 2,4-D ester with added oil. It was concluded that the rate of 2,4-D amine alone which provided excellent control of the weed was sufficiently high that it did not permit improvement of effect by additives. Consequently the following experiment employed only 0.28 kg/ha of 2,4-D amine instead of 0.35 kg/ha.

5b. 2,4-D amine on Tartary buckwheat

Addition of 11.23 l/ha (1 imp gal/A) of rapeseed oil to 2,4-D amine decreased the average number of surviving Tartary buckwheat plants by 70% over 2,4-D amine alone and by 60% over 2,4-D amine plus emulsifier (Table 8). Thus it was concluded that it was not just the emulsifier that increased the phytotoxicity of the 2,4-D amine. The increase in phytotoxicity was mostly the effect of added rapeseed oil. It also appeared that 2.81 l/ha of oil was not

Table 8. Effects of rapeseed oil added to 2,4-D amine (0.28 kg/ha) on Tartary buckwheat. (Means of 5 replications).

Treatments	Tartary Buckwheat (per pot) Average Height (cm)	Dry Weight (g)	Average number of surviving plant
Control	17.0 a*	2.45 a	15.0
2,4-D amine	9.2 b	1.10 b	12.2
2,4-D amine + emulsifier	6.6 c	0.65 c	9.2
2,4-D amine + 2.81 l/ha oil	5.2 c	0.64 c	9.6
2,4-D amine + 11.23 l/ha oil	3.6 d	0.21 d	3.6

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

enough oil to increase phytotoxicity any more than the increase induced by added emulsifier.

The increase in phytotoxicity of 2,4-D amine with the addition of rapeseed oil may be due only to increased penetration of herbicide caused by the solubilizing action of the oil on the cuticle layer of the Tartary buckwheat plant as was noted earlier in the microscopic examination of Tartary buckwheat leaves sprayed with 2,4-D in an oil-water emulsion (Section 2 of Laboratory Experiments).

Jansen (1964) also found that the phytotoxicity of the triethanolamine salt formulation of 2,4-D was greater on soybean (*Glycine max* (L.) Merr.) when applied in a non-phytotoxic oil than in water.

5c. Barban on wheat, rapeseed, and wild oats

The results of the first two experiments, 5c-1, 5c-2, were similar so only the results of the experiment using Triton X-363M as emulsifier are presented here (Table 9).

Although there were no significant differences between any of the barban treatments, there was a trend for barban with added rapeseed oil to decrease dry weight of wild oats more than did barban alone (Fig. 7 and 8).

In the third experiment, 5c-3, the wild oat plants were left for a longer time before harvest so some of the plants in the barban alone and barban plus emulsifier treatments had recovered and were even headed out. There were no plants headed out in the barban plus rapeseed oil treatments. Thus in this case there was a significant difference between barban alone and barban with added rapeseed oil [redacted]ffects of the addition of rapeseed oil on the phytotoxicity of barban (0.17 kg/ha) to wild [redacted] and wheat. (Means of 3 replications).

Treatment	Wheat (average per pot)			Wild Oats (average per pot)		
	Number of culms	Plant Height (cm)	Dry Weight (g)	Number of culms	Plant Height (cm)	Dry Weight (g)
Control	29	70.7 a*	13.99 a	32 a	83.3 a	13.50 a
Barban	29	68.3 a	14.98 a	17 b	39.8 b	3.06 b
Barban + emulsifier	28	69.7 a	15.17 a	14 b	49.0 b	2.37 b
Barban + 11.23 l/ha oil	29	70.3 a	17.35 a	13 b	34.5 b	1.22 b

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan, 1955).

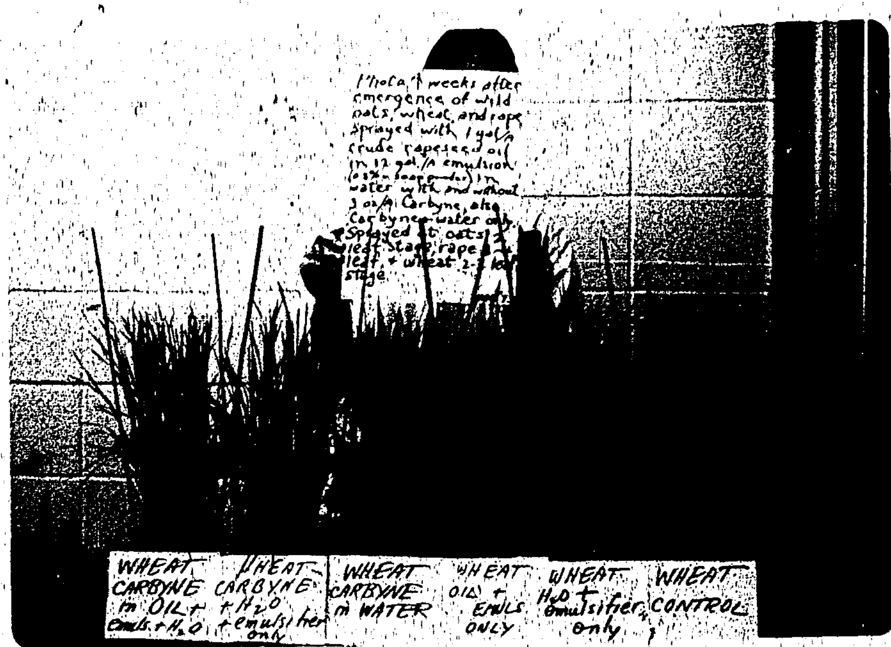

Figure 7. Wheat sprayed with barban (Carbyne) 0.17 kg/ha with and without added rapeseed oil. Note no effect of any of the barban treatments on the wheat 28 days after spraying it at the 2-3 leaf stage.

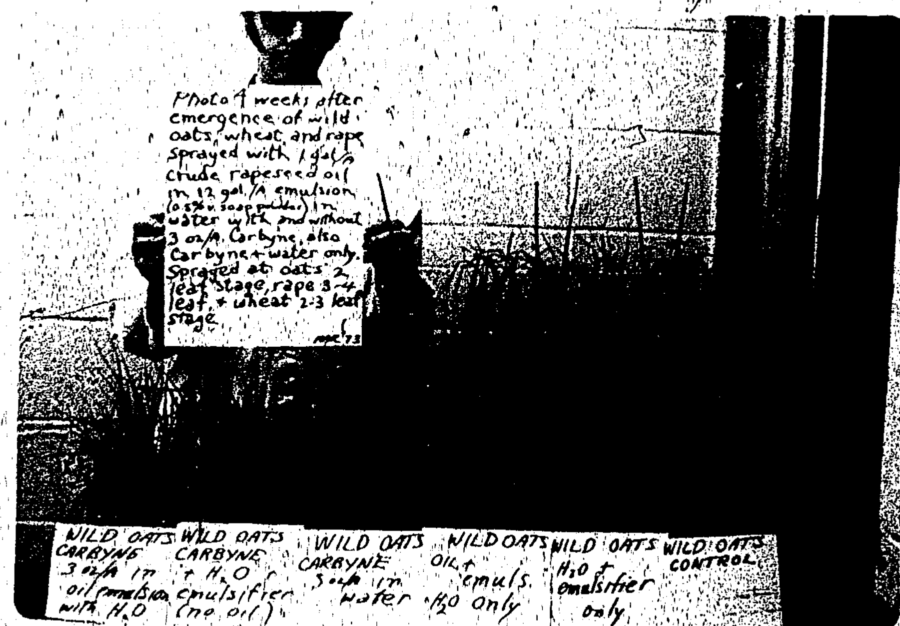

Figure 8. Wild oats sprayed with barban (Carbyne) 0.17 kg/ha with and without added rapeseed oil. Note only slight difference from barban applied in oil-water emulsion as compared with barban in water. Photo 28 days after spraying of wild oats at 2-leaf stage.

(Table 10).

On balance the results of the various experiments show a tendency for added rapeseed oil to increase the phytotoxicity of barban on wild oats.

Nalewaja (1972) showed that oil additives tended to increase wild oat control with barban. The oils he used were Sunoco Superior Spray Oil 11E and linseed oil (Bio Veg).

5d. Dalapon and TCA on green foxtail, rapeseed, and barley

In both of the first two experiments, 5d-1, 5d-2, there was no significant difference among the dalapon treatments, although there was a tendency for the treatment with rapeseed oil added to dalapon to cause better control of green foxtail than dalapon alone or dalapon plus emulsifier. None of the dalapon treatments had any effect on rapeseed but dalapon with added rapeseed oil or emulsifier, especially the soap powder, significantly reduced the dry weight of barley (Tables 11 and 12).

In the experiment using soap powder as the emulsifier, 5d-1, there was a significantly greater reduction of green foxtail dry weight and height using TCA with added rapeseed oil than with TCA alone. There was no significant effect with any of the TCA treatments on either rapeseed or barley (see Table 11). In the experiment using Triton X-363M as the emulsifier, 5d-2, there was no significant difference among the TCA treatments although there was a slight tendency for the treatment with rapeseed oil added to TCA to result in better control of green foxtail than from TCA alone (Figs. 9 and 10) (Table 12).

Table 10. Effect of two rates of rapeseed oil on the phytotoxicity of barban (0.17 kg/ha) to wild oats. (Means of 5 replications).

Treatments	Wild Oats (average per pot)	
	Number of plants	Dry weight (g)
Control	23	13.89 a*
Barban	11	9.22 ab
Barban + emulsifier	10	6.94 b
Barban + 2.81 l/ha oil	5	0.95 c
Barban + 11.23 l/ha oil	7	1.36 c

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 11. Effect of dalapon (0.56 kg/ha) and TCA (0.56 kg/ha) with added rapeseed oil, using soap powder as the emulsifier, on green foxtail, rapeseed, and barley. (Means of 3 replications).

Treatments	Green Foxtail (average per pot)		Rapeseed (average per pot)		Barley (average per pot)	
	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)
Control	39.7	7.35 a*	28.3	8.65 a	28.7	11.95 a
Dalapon	13.1	3.29 b	28.7	9.39 a	25.3	10.46 ab
Dalapon + emulsifier	9.3	3.87 b	29.0	8.95 a	17.0	6.96 c
Dalapon + 11.23 l/ha oil	7.3	2.17 b	29.0	8.58 a	16.3	8.15 bc
TCA	23.3	7.51 a	27.7	9.08 a	29.0	12.66 a
TCA + emulsifier	17.0	4.44 ab	27.0	9.02 a	25.7	10.81 a
TCA + 11.23 l/ha oil	9.9	2.94 b	25.7	8.70 a	24.7	11.67 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 12. Effect of dalapon (0.56 kg/ha) and TCA (0.56 kg/ha) with added rapeseed oil, using Triton X-363M as the emulsifier, on green foxtail, rapeseed, and barley. (Means of 3 replications).

Treatments	Green Foxtail (average per pot)		Rapeseed (average per pot)		Barley (average per pot)	
	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)
Control	43.0	6.59 a*	69.0	12.01 a	65.7	14.32 a
Dalapon	11.3	1.26 b	73.3	11.39 a	56.3	13.10 a
Dalapon + emulsifier	12.7	1.23 b	68.3	11.23 a	54.3	12.68 a
Dalapon + 11.23 l/ha oil	10.0	0.19 b	77.7	11.43 a	54.0	9.57 b
TCA	30.0	7.63 a	72.7	11.05 a	65.0	14.70 a
TCA + emulsifier	32.5	6.43 a	73.0	9.88 a	66.7	15.85 a
TCA + 11.23 l/ha oil	31.0	6.23 a	67.0	11.75 a	64.0	14.33 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

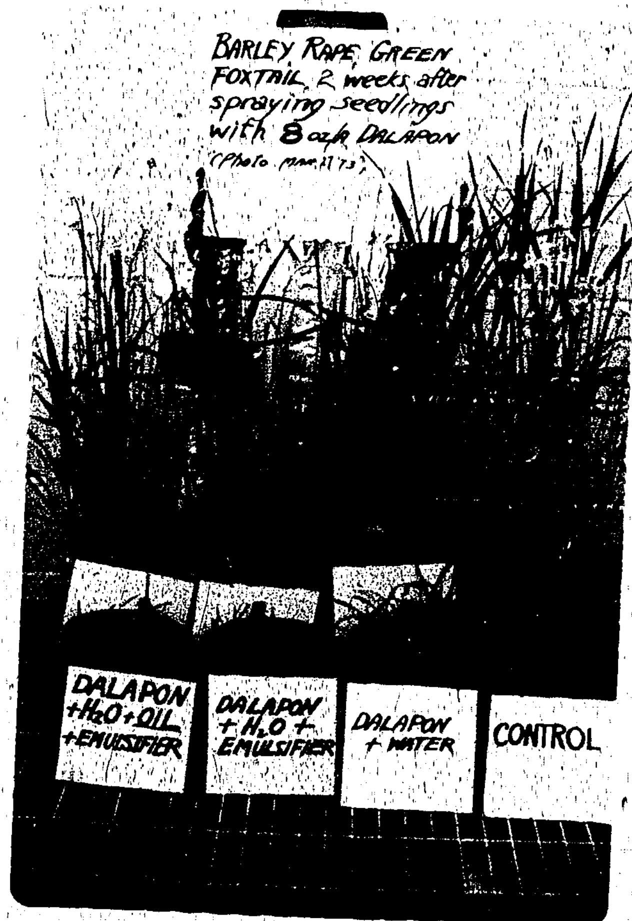

Figure 9. Barley, rapeseed, and green foxtail 15 days after spraying with dalapon 0.56 kg/ha. Note the greater reduction in growth of the green foxtail (front row) treated with dalapon plus oil than after dalapon alone. Stage of growth at spraying time was 2-3 leaf stage for all species.

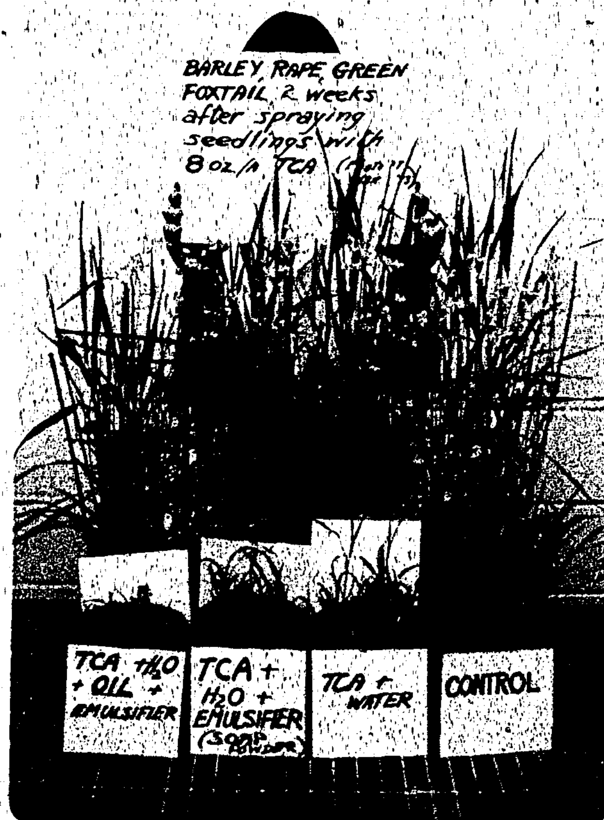

Figure 10. Barley, rapeseed, and green foxtail 15 days after spraying with TCA 0.56 kg/ha. Note the greater reduction in growth of the green foxtail (front row) treated with TCA plus oil than after TCA alone. Growth stages at spraying time were the same as for Figure 9.

The results of the third experiment, 5d-3, were similar to those of experiment 5d-2 both involving Triton X-363M as the emulsifier. There were no significant differences yet there were tendencies for dalapon plus rapeseed oil to cause more reduction in dry weight of green foxtail than dalapon alone. There were no appreciable differences between TCA treatments. Only the dalapon plus rapeseed oil treatment adversely affected the barley dry weight.

The fourth experiment, 5d-4, showed a significant difference among both the dalapon treatments and the TCA treatments. In both cases herbicide with added rapeseed oil induced better control of the green foxtail than herbicide alone or herbicide plus emulsifier (Table 13).

Thus it was concluded from this series of experiments that added rapeseed oil did tend to increase the phytotoxicity of dalapon and TCA on green foxtail. (In neither experiment was there any effect of the TCA treatments on rapeseed or barley.)

Nalewaja (1974) has shown an increase in the phytotoxicity of TCA with added linseed oil on yellow foxtail (*Setaria glauca* (L.) Beauv.).

5e. <u>MCPA amine on Tartary buckwheat, wheat, and hemp nettle</u>

It was concluded from the first experiment, 5e-1, that MCPA amine with added rapeseed oil was as good as the recommended field treatment of a tank mix of MCPA and linuron. MCPA amine with added rapeseed oil caused 40% greater reduction in dry weight of Tartary buckwheat than did MCPA amine alone or with added emulsifier. The addition of rapeseed oil to MCPA appeared to have little effect on the wheat (Table 14).

Table 13. The effect of Dalapon (0.45 kg/ha) and TCA (1.4 kg/ha), with and without added rapeseed oil, on green foxtail (Means of 4 replications).

Treatment	Green Foxtail (average per pot)	
	Plant height (cm)	Dry weight (g)
Control	17.25 a*	5.56 a
Dalapon	13.75 ab	5.00 a
Dalapon + emulsifier	9.75 bc	4.68 ab
Dalapon + 2.81 l/ha oil	4.62 cd	3.62 b
Dalapon + 11.23 l/ha oil	3.38 d	3.34 c
TCA	6.12 cd	3.83 b
TCA + emulsifier	4.38 d	3.56 b
TCA + 11.23 l/ha oil	3.75 d	3.26 c

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 14. Effects of the addition of rapeseed oil to MCPA amine (0.35 kg/ha) on Tartary buckwheat and wheat. (Means of 4 replications).

Treatments	Tartary buckwheat (average per pot) Plant height (cm)	Dry weight (g)	Wheat (average per pot) Plant height (cm)	Dry weight (g)
Control	32.5	11.47 a*	31.2	8.31 a
MCPA	13.0	9.64 b	32.8	8.22 a
MCPA + emulsifier	13.5	9.44 b	32.5	7.55 a
MCPA + 11.23 l/ha oil	11.0	5.68 c	33.8	7.67 a
MCPA + 0.14 kg/ha linuron	15.2	6.06 c	34.8	7.04 a

*Means followed by the same letter are not significantly different at the 1% level using Duncan's Multiple Range Test (Duncan, 1955).

In the second experiment, 5e-2, in all cases with the weed species MCPA amine with added rapeseed oil had the greatest effect. MCPA amine plus added rapeseed oil caused a 39% greater reduction and dry weight of hemp nettle than MCPA amine alone, and a 17% greater reduction than MCPA amine plus emulsifier[1] (Fig. 11) or MCPA amine plus linuron. MCPA amine plus added rapeseed oil resulted in a 44% greater reduction in dry weight of Tartary buckwheat than MCPA amine alone, a 25% greater reduction than MCPA amine plus emulsifier, and a 10% greater reduction than the recommended field treatment of MCPA plus linuron. There was no significant difference among any of the treatments in the seed production of wheat (Table 15).

In the third experiment, 5e-3, there were no significant differences among any of the treatments although MCPA amine plus rapeseed oil tended to give the best control. It was concluded that the lack of significance was due to the plants being in a late stage, 6-leaf stage, when sprayed.

In the fourth experiment, 5e-4, MCPA amine plus rapeseed oil at 11.23 l/ha caused a 60% greater reduction in dry weight and 34% greater reduction in height of hemp nettle than MCPA amine alone and a 53% greater reduction in dry weight and 15% greater reduction in height than MCPA amine plus emulsifier. MCPA amine plus 2.81 l/ha of rapeseed oil was not significantly different with respect to plant height and dry weight from MCPA amine alone, but did give a much higher percentage kill. MCPA amine plus 11.23 l/ha of rapeseed oil gave the greatest percentage kill of hemp nettle (Table 16). It was concluded from this experiment that 11.23 l/ha of rapeseed oil is required to cause a significant increase in the phytotoxicity of

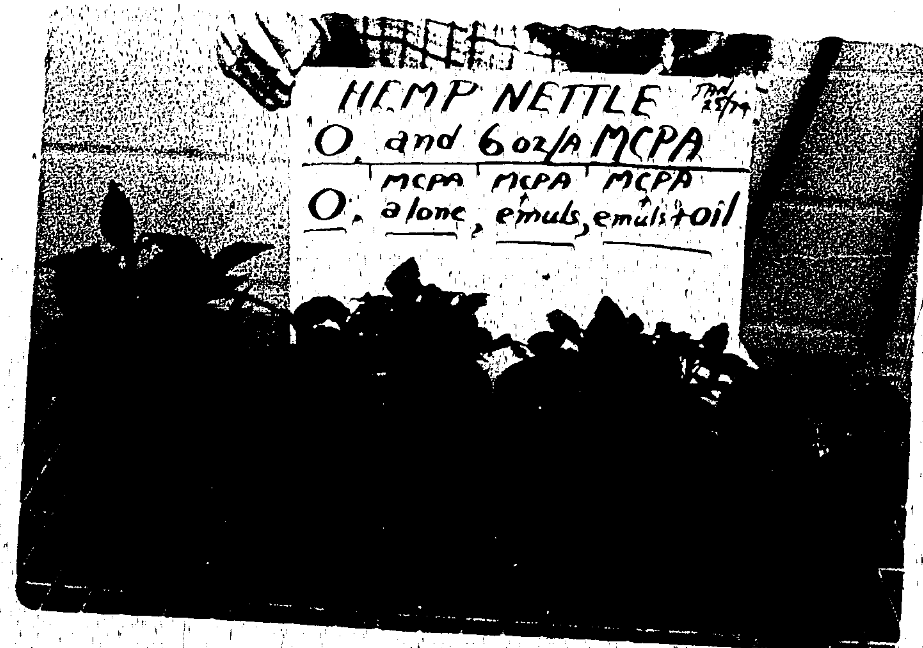

Figure 11. Hemp nettle 20 days after spraying with MCPA amine. 0.42 kg/ha at the 2-leaf stage. Note the greater reduction in growth and the presence of adventitious roots for those plants treated with MCPA plus oil (right) in contrast with those plants treated with MCPA alone (second from left).

Table 15. Effects of rapeseed oil added to MCPA amine (0.42 kg/ha) on Tartary buckwheat, wheat, and hemp nettle. (Means of 4 replications).*

Treatment	Hemp Nettle (average per pot)		Tartary Buckwheat (average per pot)		Wheat (average per pot)		
	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)	Number of heads	Number of seeds	Seed weight (g)
Control	11.8a*	4.39a	17.2a	16.94a	22.5a	422a	12.9a
MCPA	9.5b	3.08b	12.5b	12.26b	22.8a	468a	13.6a
MCPA + emulsifier	6.5c	2.56bc	9.3bc	9.09bc	23.8a	485a	14.1a
MCPA + 11.23 l/ha oil	4.4d	2.13c	8.8c	6.84c	20.2a	375a	11.7a
MCPA + 0.14 kg/ha linuron	8.2bc	2.59bc	12.5b	7.62c	23.0a	434a	14.0a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 16. Effects of different rates of rapeseed oil added to MCPA amine (0.35 kg/ha) on hemp nettle. (Means of 5 replications).

	Hemp Nettle		
	Average plant height (cm)	Plant dry weight (g)	Percent of plants killed
Control	34.4 a*	9.63 a	
MCPA	16.0 b	3.57 b	24.2
MCPA + emulsifier	12.4 bc	2.96 bc	37.6
MCPA + 2.81 l/ha oil	13.8 bc	2.85 bc	51.4
MCPA + 11.23 l/ha oil	10.6 c	1.40 c	61.4

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

MCPA amine.

General conclusions from all MCPA experiments are that the addition of rapeseed oil at 11.23 l/ha to MCPA amine significantly increased the phytotoxicity of the MCPA amine on Tartary buckwheat and hemp nettle and did not reduce MCPA selectivity for weed control use in wheat.

5f. Chloroxuron on green foxtail and faba beans

In the first experiment, 5f-1, addition of rapeseed oil to chloroxuron significantly increased the phytotoxicity of chloroxuron on green foxtail to cause complete kill. This addition of rapeseed oil, however, decreased the selectivity of chloroxuron to the extent that most of the faba beans were also killed (Table 17).

In the second experiment, 5f-2, addition of rapeseed oil to 0.84 kg/ha of chloroxuron caused a 45% greater reduction in dry weight of green foxtail than 0.84 kg/ha of chloroxuron alone and a 72% greater reduction than 0.84 kg/ha of chloroxuron plus emulsifier (Fig. 12) (Table 18).

It was concluded from this experiment, 5f-2, that the addition of oil to chloroxuron caused significantly greater reduction of dry weight of green foxtail, even at 0.28 kg/ha of chloroxuron, than followed the use of 0.84 kg/ha of chloroxuron alone or with emulsifier. It was only at the 0.28 kg/ha and 0.56 kg/ha rates of chloroxuron plus rapeseed oil that the effect on faba beans was small enough to be of negligible practical significance. Any greater dosage of chloroxuron with rapeseed oil damaged the faba beans greatly.

Table 17. Effects of chloroxuron (1.12 kg/ha) with added rapeseed oil on green foxtail and faba beans. (Means of 4 replications).

Treatment	Green Foxtail (average per pot)			Faba beans (average per pot)	
	Number of plants	Plant height (cm)	Dry weight (g)	Plant height (cm)	Dry weight (g)
Control	15	24.0 a*	11.6 a	100	48.5 a
Chloroxuron	7	19.5 a	5.8 ab	88	41.9 a
Chloroxuron + Emulsifier	6	19.0 a	3.8 b	90	43.4 a
Chloroxuron + 11.23 l/ha oil	0	0.0 b	0.0 b	80	2.0 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

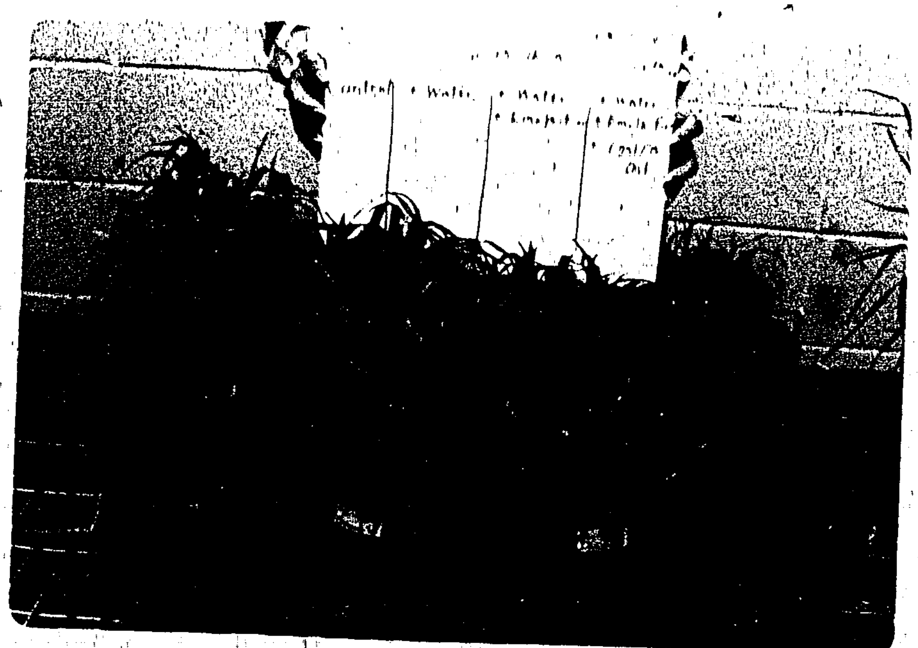

Figure 12. Green foxtail sprayed at 2-3 leaf stage with chloroxuron 0.84 kg/ha, 17 days before photographing. Note the great reduction in growth after treatment with chloroxuron plus oil (right) compared with plants treated with chloroxuron plus emulsifier (second from right) or chloroxuron alone (second from left).

Table 18. Effects of different rates of chloroxuron with added rapeseed oil on green foxtail and faba beans. (Means of 4 replications).

Treatment	Green Foxtail (average per pot) Number of plants	Plant height (cm)	Dry weight (g)	Faba beans (average per pot) Plant height (cm)	Dry weight (g)
Control	20	34.2a*	9.00a	37.5	6.90a
Chloroxuron 0.84 kg/ha	20	30.2ab	9.08a	36.2	6.23a
Chloroxuron 0.84 kg/ha + emulsifier	20	28.8ab	8.10a	39.5	6.73a
Chloroxuron 0.84 kg/ha + 11.23 l/ha oil	12	19.2c	2.23c	31.8	4.03b
Chloroxuron 0.56 kg/ha + 11.23 l/ha oil	19	21.8c	3.60c	35.0	5.95a
Chloroxuron 0.28 kg/ha + 11.23 l/ha oil	20	25.0bc	5.65b	33.5	6.35a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Thus it was found from these two experiments, 5f-1 and 5f-2, that the addition of rapeseed oil to chloroxuron greatly increased its phytotoxicity to green foxtail but reduced its selectivity with regard to faba beans.

Anderson (1968), Anderson and Ziebart (1969), and Gonnett and Riech (1971) also found that the addition of a non-phytotoxic mineral oil to chloroxuron increased weed control but also increased injury to the soybean crop.

5g. Nitrofen on stinkweed and lamb's quarters

Although there was no significant difference among the nitrofen treatments there was a tendency for the treatment with added rapeseed oil to lead to less reduction in plant dry weight than nitrofen alone or with added emulsifier (Table 19). This confirmed the results obtained in the field (see Field Experiments 2a-1, 2a-2).

5h. Benazolin on cleavers and rapeseed

Although there was no significant difference among the benazolin treatments in the first experiment, 5h-1, there was a tendency for 0.42 kg/ha of benazolin plus rapeseed oil to effect greater reduction of dry weight of cleavers than 0.42 kg/ha of benazolin alone or with emulsifier or than 0.84 kg/ha of benazolin alone. There was no significant effect on the rapeseed from any of the benazolin treatments although 0.84 kg/ha of benazolin alone had the greatest effect in reducing dry weight of rapeseed (Table 20).

In the second experiment, 5h-2, addition of 2.81 l/ha rapeseed oil to benazolin resulted in a 44% greater reduction of cleavers' dry weight than from benazolin alone and a 34% greater reduction than after benazolin plus emulsifier. Addition of 11.23 l/ha rapeseed

Table 19. Effect of nitrofen (0.56 kg/ha) with added rapeseed oil on lamb's-quarters and stinkweed. (Means of 4 replications).

Treatments	Lamb's-quarters and Stinkweed	
	Average plant height (cm)	Plant dry weight (g)
Control	9.50 a*	1.17 a
Nitrofen	3.75 c	0.45 b
Nitrofen + emulsifier	6.00 b	0.52 b
Nitrofen + 11.23 l/ha oil	5.00 bc	0.67 b

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

Table 20. Effect of benazolin with added rapeseed oil on rapeseed and cleavers. (Means of 4 replications).

Treatment	Cleavers (average per pot) Percent of plants killed	Plant height (cm)	Dry weight (g)	Rapeseed (average per pot) Plant height (cm)	Dry weight (g)
Control	0.0	50.0	12.92a*	75.0	20.40a
Benazolin 0.42 kg/ha	70.7	22.8	1.22b	73.8	19.97a
Benazolin 0.42 kg/ha + emulsifier	79.8	20.5	0.93b	71.2	19.70a
Benazolin 0.42 kg/ha + 11.23 l/ha oil	97.7	14.0	0.02b	65.0	19.89a
Benazolin 0.84 kg/ha	95.8	18.5	0.30b	71.2	17.22a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

oil to benazolin caused a 70% greater reduction of cleavers dry weight than benazolin alone, a 65% greater reduction than benazolin plus emulsifier, and a 45% greater reduction than benazolin plus 2.81 l/ha of rapeseed oil. The larger amount of rapeseed oil added to benazolin induced better control than the smaller amount. Benazolin plus 11.23 l/ha of rapeseed oil led to 89.4% kill of cleavers whereas benazolin plus 2.81 l/ha of oil caused only 65.5% kill. There was no significant effect of any of the benazolin treatments on rapeseed dry weight (Table 21). These experiments confirmed the results of field experiments 2f-1 and 2f-2.

It was concluded from these experiments and field experiments with benazolin that the addition of rapeseed oil greatly increased the phytotoxicity of benazolin on cleavers and did not seem to significantly reduce the selectivity with regard to rapeseed.

Table 21. Effect of different rates of rapeseed oil added to benazolin (0.35 kg/ha) on cleavers and rapeseed. (Means of 5 replications).

Treatment	Cleavers (per pot)				Rapeseed (per pot)	
	Number of plants	Percent plants killed	Average plant height (cm)	Plant dry weight (g)	Average plant height (cm)	Plant dry weight (g)
Control	17.0 a*	0.0	50.6 a	13.77 a	63 a	11.93 a
Benazolin	12.8 b	24.7	41.8 b	6.16 b	65 a	13.91 a
Benazolin + emulsifier	11.6 b	31.8	33.4 b	5.28 b	62 a	12.53 a
Benazolin + 22.81 l/ha oil	5.8 c	65.9	37.6 b	3.46 bc	67 a	11.70 a
Benazolin + 11.23 l/ha oil	1.8 d	89.4	21.0 c	1.87 c	66 a	13.78 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

SUMMARY OF GROWTH CHAMBER AND GREENHOUSE EXPERIMENTS

The studies employing different fractions of rapeseed oil indicated that there was no effect of these oils on the test plant species. In view of this finding, it was decided that the crude rapeseed oil, being least expensive, would be used in further studies. The crude rapeseed oil could be sprayed on the test species without damage from rates to at least 112.33 l/ha (10 Imp gal/A). The selected emulsifier, Triton X-363M, had no adverse effects on rapeseed plants. From the studies involving rapeseed oil added to herbicides used on the species included in these tests, it was found that the oil significantly increased the phytotoxicity of 2,4-D amine, MCPA amine, chloroxuron and benazolin; that the oil tended to increase the phytotoxicity of barban, dalapon and TCA; and that the oil tended to decrease the phytotoxicity of nitrofen.

III. FIELD EXPERIMENTS

A. Materials and Methods

1. General procedures.

Field experiments were conducted on fallowed Malmo clay loam soil at the University of Alberta Research Station at Ellerslie in the summers of 1973 and 1974. Crops and some species of weeds, Tartary buckwheat and wild oats, were planted with a 1.8 m (6 foot) press drill with a 15.24 cm (6 in) spacing. Cleavers and green foxtail were planted with a motorized V-belt seeder with a 15.24 cm spacing. All cropped plots were fertilized with 84 kg/ha (75 lb/A) of 11-55-0 fertilizer. Herbicides were applied using a bicycle-wheeled plot sprayer with a 1.5 m (5 foot) boom containing 3 nozzles. Volumes of 56.16 l/ha (5 Imp gal/A) were applied with Tee Jet 650067 nozzles and volumes of 112.33 l/ha (10 Imp gal/A) were applied with Tee Jet 65015 nozzles. Pressure was obtained from a compressed air tank with a regulator to permit 2.81 kg/cm^2 (40 psi) to the spray system. Speed was gauged with a speedometer to 5.3 km/hr (3.3 mph). Treatments included an unsprayed control, herbicide sprayed in water, herbicide sprayed in water with emulsifier added, and herbicide sprayed in a rapeseed oil-water emulsion. Rapeseed oil was added at 11.23 l/ha (1.0 Imp gal/A) in 112.33 l/ha (10 Imp gal/A) total volume. In 1974 rapeseed oil was also added at a rate of 2.81 l/ha (0.25 Imp gal/A). In all cases except where noted, oil was emulsified using Triton X-363M emulsifier at 5% v/v of the oil. In the preparations including only emulsifier with herbicide the proportion of emulsifier was the same as that used with the 11.23 l/ha rate of oil. Herbicide rates used were less than normally recommended field rates in order to permit detection of any increased effect of added rapeseed oil. Treatments were replicated 4 times on 1.8 m x 5.5 m (6 ft x 18 ft) plots in 1973 and on 1.8 m x 3.7 m (6 ft x 12 ft) plots in 1974. Plots were smaller in 1974 due to limited land availability. For most experiments visual injury scores were recorded three times during the summer. Harvesting was done using hand tools on an area 0.84 m^2 (1 yd^2) from each plot. Harvest data consisted of plant dry weight of top growth for the weeds and seed yield weight for the crops.

In 1973, crops and weeds were planted in separate areas so the effect of the rapeseed oil added to herbicides could be clearly distinguished. This eliminated the confusing effect of competition between weeds and crops. If the oil was beneficial in relation to control of the weeds alone presumably the results would be even more beneficial with the weeds in the crop, owing to the added effect of crop competition. With this rationale the crops and weeds were planted together in 1974 to simulate practical conditions.

4. 2. Herbicide treatments with and without rapeseed oil additive in the field.

2a. <u>2,4-D amine on Tartary buckwheat, barley, and wheat</u>

2a-1. Plots were seeded with Conquest barley on May 16 and with Tartary buckwheat in a separate adjacent experiment on May 31, 1973. The barley was sprayed at the 5-6 leaf stage on June 19, buckwheat at the 2-3 leaf stage on June 22 with 0.56 kg/ha (8 oz/A) of the dimethylamine salt of 2,4-D with and without added rapeseed oil at 11.23 l/ha (1.0 Imp gal/A). Total spray volume was made up to 112.33 l/ha (10 Imp gal/A) with water. Triton X-207 emulsifier was used at 5% v/v of the oil in this experiment because the supply of Triton

X-363M had been exhausted. The esteminc formulation of 2,4-D was used in water only, for comparison with the dimethylamine preparation of 2,4-D made by the same company. Conditions for spraying on both dates were good; temperature 21.1°C (70°F) and 18.3°C (65°F) respectively, light winds both days, and no rain fell within the twenty-four hours after spraying. Visual injury scores were recorded four times during the summer. Tartary buckwheat was harvested on August 15. Barley was cut on August 21 and threshed on August 30, 1973.

2a-2. In 1974, Thatcher wheat was seeded on May 24 at right angles to the rows of Tartary buckwheat seeded 3 days earlier. Rates of 2,4-D used were 0.42 kg/ha (6 oz/A), 0.56 kg/ha (8 oz/A), and 0.70 kg/ha (10 oz/A) alone and with added rapeseed oil at 2.81 l/ha (0.25 imp gal/A) and 11.23 l/ha (1.0 imp gal/A). Uniform stands of crop and weeds were sprayed on June 17 when the wheat was in the 4-leaf stage with longest leaves averaging 16 cm. At this time the Tartary buckwheat had 3 to 5 leaves on plants about 10 cm tall. Conditions for spraying were ideal: temperature 23.9°C (75°F), wind 8 km/hr (5 mph), and no rain fell within twenty-four hours after spraying. Tartary buckwheat was harvested on August 15. Wheat was cut on September 17 and threshed on September 26, 1974.

2b. Barban on wild oats, barley, and rapeseed

Barban was tested in the field only in 1973. The 1974 experiment was not completed owing to very poor germination of the wild oats.

Wild oats were seeded on May 15, 1973. In adjacent but separate plots Conquest barley was seeded on May 16 and Span rapeseed on May 17. Plants were sprayed with 0.24 kg/ha (3.5 oz/A) of barban on June 6 when wild oats were in the 2-leaf stage, barley in the 3-4 leaf stage, and rapeseed in the 2-4 leaf stage. The spray was applied at 3.16 kg/cm (45 psi) with the boom tilted forward at a 45° angle. Conditions at time of spraying were ideal: temperature 22.2°C (72°F), wind 8 km/hr (5 mph) and no rain fell in the twenty-four hours following spraying. Wild oats were harvested August 14, barley August 21, and rapeseed August 23.

2c. <u>Dalapon and TCA on green foxtail, barley, rapeseed, and oats</u>

2c-1. Conquest barley was seeded on May 16, Span rapeseed on May 17, and green foxtail on June 5, 1973 each in separate but adjacent plots. Dalapon at 0.84 kg/ha (0.75 lb/A) and TCA at 1.12 kg/ha (1.0 lb/A) with and without added rapeseed oil at 14.23 l/ha was sprayed on barley and rapeseed on June 13 when barley was in 5-6 leaf stage and rapeseed in 3-6 leaf stage. Conditions for spraying were fairly good with temperature 20°C (68°F) and light wind--less than 9.6 km/hr (6 mph). There was a trace of precipitation within the twenty-four hours after spraying. Green foxtail in the 2-3 leaf stage, 3 cm tall, was sprayed on June 26. Conditions were good at spraying time: temperature 16.7°C (62°F), light wind, and no rain fell in the twenty-four hours following spraying. Barley was harvested on August 21, rapeseed on August 23, and green foxtail on August 28.

2c-2. In 1974, Garry oats were seeded on May 27. The same day 4 rows per plot of green foxtail were seeded between the rows of oats. On June 17 plots were sprayed with 1.12 kg/ha (1.0 lb/A) of TCA when both species were in the 3-4 leaf stage. The green foxtail plants were 3.5 cm tall and the oats 17 cm tall. Rapeseed oil was added at the rate of 2.81 l/ha (0.25 Imp gal/A) or 11.23 l/ha (1.0 Imp gal/A). Conditions at spraying time were ideal: temperature 23.9°C (75°F), light wind, and no rainfall during the twenty-four hours following spraying. Green foxtail was harvested on August 14 and oats on August 30, 1974.

2d. MCPA amine on Tartary buckwheat and oats

Garry oats were seeded at Ellerslie on May 27, 1974, at right angles to the rows of Tartary buckwheat seeded six days earlier. Uniform stands of crop and weeds were sprayed with 0.56 kg/ha (8 oz/A) of MCPA amine with and without added rapeseed oil at 11.23 l/ha on June 17 when the crop was in the 2-3 leaf stage with the longest leaves averaging 18 cm. At this time the Tartary buckwheat had 3 to 5 leaves on plants about 10 cm tall. A frequently recommended field treatment was included for comparison. This was a tank mix of 0.56 kg/ha MCPA plus 0.28 kg/ha (4 oz/A) of linuron. Conditions at spraying time were ideal: temperature 23.9°C (75°F), wind 9.6 km/hr (6 mph), and no rain fall during the twenty-four hours following spraying. Visual injury scores were recorded four times during the summer. Tartary buckwheat was harvested on August 2 and oats on August 30.

2e. Nitrofen on Tartary buckwheat and rapeseed

2e-1. Span rapeseed was planted on May 17[illegible] adjacent comparable experiment with Tartary buckwheat was established on May 31, 1973. Nitrofen at 1.12 kg/ha (1.0 lb/A) with and without added rapeseed oil was sprayed on the rapeseed at 3-6 leaf stage on June 13 and on Tartary buckwheat at 2-3 leaf stage on June 22. Conditions for spraying on June 13 were fairly good: temperature was 20°C (68°F) with light wind but there was a trace of precipitation within the twenty-four hours after spraying. On June 22 temperature was 18.3°C (65°F) and there was light wind. No rain fell within twenty-four hours of spraying. Visual injury scores were recorded four times during the summer. Tartary buckwheat was harvested August 15 and rapeseed on August 23.

2e-2. Span rapeseed was seeded at Ellerslie on May 27, 1974, at right angles to Tartary buckwheat seeded five days earlier. Plots were sprayed with 1.34 kg/ha (19.2 oz/A) of nitrofen with and without added rapeseed oil on June 18 when the rapeseed was in the 3-6 leaf stage on plants 7 cm tall. The Tartary buckwheat was in the 3-5 leaf stage on plants 11 cm tall. Conditions at the time of spraying were ideal: temperature 26.7°C (80°F), wind 6.4 km/hr (4 mph), and no rain fell within twenty-four hours following spraying. Visual injury scores were recorded a week following spraying. Plants were harvested on August 21 and rapeseed threshed on September 3.

2f. Benazolin on cleavers and rapeseed

2f-1. On June 5, 1973, cleavers were seeded in plots involving 4 rows 15 cm apart, 5.4 m long, per plot. Benazolin at 0.56 kg/ha (8 oz/A) with and without rapeseed oil was sprayed on June 27 when the cleavers were in the first whorl stage, 2.5 cm tall. Conditions at spraying time were ideal: temperature 21.1°C (70°F), wind 6.4 km/hr (4 mph), and no rain fell during the twenty-four hours following spraying. Cleavers were harvested on August 29.

2f-2. Span rapeseed was seeded in two adjacent locations at Ellerslie farm on May 28, 1974. The next day four rows of cleavers per plot were seeded between the rows of rapeseed in one of the locations. In a third area having no rapeseed four rows of cleavers per plot were seeded alone. On June 19 plots were sprayed with benazolin at 0.42 kg/ha (6 oz/A), 0.56 kg/ha (8 oz/A), and 0.70 kg/ha (10 oz/A) with and without rapeseed oil added to 2.81 l/ha (0.25 Imp gal/A) or 11.23 l/ha (1.0 Imp gal/A). The cleavers were in the 1-2 whorl stage, 4.5 cm tall. The rapeseed was in the 4-6 leaf stage, 8.5 cm tall. Conditions were ideal for spraying: temperature 23.9°C (75°F), wind 4.8 km/hr (3 mph), and no rain fell within the twenty-four hours after spraying. The plots with cleavers alone were harvested on August 13, those with rapeseed and cleavers on August 22, and the plots with rapeseed alone, on August 23.

B. Results, Discussion, and Conclusions

(Note: Topic 1. "General procedures", was completed under "Materials and Methods").

2. Herbicide treatments with and without rapeseed oil additive in the field.

2a. 2-4,D amine on Tartary buckwheat, barley, and wheat

2a-1. In 1973, the 2,4-D amine plus rapeseed oil treatment caused the greatest reduction in dry weight of Tartary buckwheat, about 40% more reduction than that caused by 2,4-D amine alone or plus emulsifier (Table 22). The visual scores for Buckwheat in August were lower than in July owing to an unusually wet season, 14.68 cm (5.78 in) of rain between July 10 and August 10, which encouraged revival of some of the plants growing without crop competition in these plots. It can be anticipated that the weed control would have been even better had crop competition been involved but as noted earlier these experiments were designed to avoid such complications of interpretation. None of the treatments had any adverse affect on the barley (Table 22).

2a-2. During the summer of 1974 in the experiment having Tartary buckwheat growing with Thatcher wheat, there was slight reduction of height and slight delay in heading of the wheat crop after herbicide treatments including added rapeseed oil. Data for grain harvested September 18, however, showed no significant differences between any of the 2,4-D treatments and the handweeded control. There was a greater than 50% increase in seed yield after 2,4-D treatments compared with the weedy control (Table 23). Addition of rapeseed oil greatly increased the affect of 2,4-D.

Table 22. Effect of 2,4-D amine (0.56 kg/ha) with added rapeseed oil on Tartary buckwheat and barley, 1973. (Means of 4 replications).

Treatment	Tartary Buckwheat: Visual injury scores (0-9 scale)** June 26	July 4	July 10	Aug 10	Dry weight Aug 16 g/m^2	Barley grain yield g/m^2***
Control	0	0	0	0	539 a*	380 a
2,4-D amine	3	4	5	3	350 b	395 a
2,4-D amine + emulsifier	5	5	5	4	360 b	423 a
2,4-D amine + 11.23 l/ha oil	5	6	5	5	211 c	383 a
Estemine 0.56 kg/ha	3	5	5	3	279 bc	404 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**0 = no effect, 9 = complete kill.

***Results from yd^2 (0.84 m^2) extrapolated to m^2.

Table 23. Effect of different rates of 2,4-D amine with added rapeseed oil on Tartary buckwheat in wheat, 1974. (Means of 4 replications).

Treatments	Tartary Buckwheat Number of plants/m^2	Tartary Buckwheat Dry weight g/m^2	Tartary Buckwheat Plant height cm	Wheat grain yield g/m^2**
Control (weed-free)	0	-	-	443 a
Control (weedy)	145 a*	373 a	69 a	248 b
2,4-D 0.42 kg/ha	100 b	79 bcd	38 bc	434 a
2,4-D + emulsifier	67 c	46 bcd	32 c	439 a
2,4-D + 2.81 l/ha oil	30 efg	19 cd	26 cde	432 a
2,4-D + 11.23 l/ha oil	10 fg	2 d	15 ef	398 a
2,4-D 0.56 kg/ha	60 cd	45 bcd	32 c	399 a
2,4-D + emulsifier	35 def	24 cd	28 cd	424 a
2,4-D + 2.81 l/ha oil	19 fg	7 d	19 ef	398 a
2,4-D + 11.23 l/ha oil	4 g	1 d	13 f	409 a
2,4-D 0.70 kg/ha	55 cde	43 bcd	29 cd	440 a
2,4-D + emulsifier	26 fg	13 d	22 def	294 a
2,4-D + 2.81 l/ha oil	10 fg	7 d	22 def	414 a
2,4-D + 11.23 l/ha oil	2 g	1 d	12 f	375 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from yd^2 (0.84 m^2) extrapolated to m^2.

amine on Tartary buckwheat as shown by the decrease in numbers of plants compared with those remaining after treatments with 2,4-D alone or with emulsifier. All rates of 2,4-D with 11.23 l/ha of added rapeseed oil decreased the number of plants by 90%, or more, than did those rates of 2,4-D alone and by 85%, or more, than did those rates of 2,4-D with emulsifier. Even the addition of 2.81 l/ha of rapeseed oil to 2,4-D decreased the number of plants by 68-83% over 2,4-D alone. Dry weight and height of Tartary buckwheat also showed similar trends (Table 23).

From the results of these 2 experiments, 2a-1 and 2a-2, it was concluded that the addition of rapeseed oil greatly increased the phytotoxicity of 2,4-D amine on Tartary buckwheat but did not significantly affect its selectivity with respect to barley and wheat.

Comparative costs of 0.42 kg/ha (6 oz/A) of 2,4-D amine with added rapeseed oil and 0.70 kg/ha (10 oz/A) of 2,4-D amine alone were estimated (Table 24). Although the cost of the 2,4-D with rapeseed oil treatment was higher and it either slightly reduced or did not improve wheat yield compared to 2,4-D alone, it did however provide much greater weed control. Owing to the fact that it is very difficult or impossible to screen Tartary buckwheat seed from wheat grain, the amount of control of this weed in the crop is an important consideration apart from any potential improvement of grain yield.

2b. Barban on wild oats, barley, and rapeseed

Barban with added rapeseed oil did not have as much effect on wild oats as did barban with emulsifier. Both these

Table 24. Extent of control of Tartary buckwheat in wheat in relation to costs of treatment with 2,4-D amine with and without rapeseed oil.

Treatment	Estimated Cost $/A*	% Weed Control (Expt. 2a-2)	Crop Yield lb/A**	(Expt. 2a-2) bu/A
Weedy Control	-	-	2217	37.0
2,4-D amine 10oz/A alone (0.70 Kg/ha)	1.25	62	3944	65.7
2,4-D amine 6 oz/A + oil (0.42 kg/ha)	3.90	93	3560	59.3

*Cost per acre X 2.471 = cost per hectare.

Costs based on the prices of herbicide, oil and emulsifier in June, 1974.

**Pounds per acre X 1.12 = kilograms per hectare treatments were significantly different from barban alone (Table 25). Thus it was concluded that it was the emulsifier and not the oil that was having the most effect on the phytotoxicity of barban on wild oats. There was no adverse effect of any of the barban treatments on the seed yield of rapeseed or barley.

2c. Dalapon and TCA on green foxtail, barley, rapeseed, and oats

2c-1. The results from the 1973 experiment did not show any adverse effect on the rapeseed with either chemical or on barley with TCA. Dalapon with added emulsifier or oil tended to affect the grain yield of the barley. There were no significant differences among the dalapon treatments or among the TCA treatments on the green foxtail. However, with both dalapon and TCA, herbicide with added rapeseed oil appeared to cause more dry weight reduction than herbicide alone. Herbicide with emulsifier tended to cause even more reduction (Table 26). Thus it appeared that even though the difference was not statistically significant the emulsifier rather than the oil had the most effect on the phytotoxicity of the dalapon and TCA.

2c-2. In the 1974 experiment, similar results were obtained with TCA on green foxtail in oats. TCA with 11.23 l/ha of added rapeseed oil resulted in more control of green foxtail than TCA alone but TCA with emulsifier caused even better control than TCA with oil. TCA with 2.81 l/ha of rapeseed oil was similar to TCA with emulsifier (Table 27). There was no adverse effect of any of the TCA treatments on the grain yield of oats.

It was concluded from these two experiments, 2c-1 and 2c-2, that

Table 25. Effects of barban (0.24 kg/ha) with added rapeseed oil on wild oats, barley, and rapeseed; 1973. (Means of 4 replications).

Treatment	Wild Oats: Plant height cm	Wild Oats: Number of culms/m^2	Wild Oats: Dry weight g/m^2	Barley grain yield g/m^2	Rapeseed crop yield g/m^2**
Control	122	364	690 a*	380 a	186 a*
Barban	125	398	740 a	448 a	183 a
Barban + emulsifier	116	140	200 b	386 a	204 a
Barban + 11.23 l/ha oil	115	257	380 b	421 a	201 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from yd^2 (0.84 m^2) extrapolated to m^2.

Table 26. Effects of dalapon (0.84 kg/ha) and TCA (1.12 kg/ha) with added rapeseed on green foxtail, rapeseed, and barley, 1973. (Means of 4 replications).

Treatments	Green Foxtail		Rapeseed	Barley
	Plant height cm	Dry weight g/6m**	Crop yield g/m²	Grain yield g/m²***
Control	80	872 a	186 a	380 a
Dalapon	20	76 c	169 a	421 a
Dalapon + emulsifier	15	88 c	164 a	336 a
Dalapon + 11.23 l/ha oil	22	49 c	190 a	329 a
TCA	42	218 b	157 a	383 a
TCA + emulsifier	37	156 b	188 a	404 a
TCA + 11.23 l/ha oil	39	163 b	209 a	386 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from 2 rows 10 ft. (3m) long.

***Results from yd² (0.84 m²) extrapolated to m².

Table 27. Effect of TCA (1.12 kg/ha) with added rapeseed oil on green foxtail in oats, 1976. (Means of 4 replications).

Treatments	Green Foxtall Plant height cm	Green Foxtall Dry weight g/3.6m**	Oats grain yield g/m²***
Control (weed-free)	-	-	402 a
Control (weedy)	42.5 a*	48.6 a	412 a
TCA	27.5 b	38.9 b	414 a
TCA + emulsifier	11.5 e	8.8 d	445 a
TCA + 2.81 l/ha oil	16.2 d	9.9 d	426 a
TCA + 11.23 l/ha oil	16.[illegible]	17.7 c	439 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from 4 rows 3 ft (.9 m) long.

***Results from yd^2 (0.84 m^2) extrapolated to m^2.

rapeseed oil did not significantly increase the phytotoxicity of dalapon or TCA under field conditions.

2d. MCPA amine on Tartary buckwheat and oats

The recommended treatment of MCPA plus linuron caused more visible damage to the crop than the other MCPA treatments. Data for grain harvested August 30, however, showed no significant differences between any of the treatments and the handweeded control. Results from all treatments were more than 100% better than those for the weedy control. MCPA amine alone did not give as effective control of Tartary buckwheat as MCPA plus linuron. Addition of rapeseed oil increased the effect of the MCPA amine on the Tartary buckwheat as shown for example by over 75% decrease in the number of plants compared with those remaining for treatments with MCPA amine alone. MCPA amine with added rapeseed oil was also almost 50% better than MCPA plus linuron in controlling Tartary buckwheat. The enhancement by rapeseed oil of MCPA on Tartary buckwheat was also shown by reduction of height and dry weight as compared to MCPA alone (Table 28).

It was concluded that rapeseed oil added to MCPA amine significantly increased the phytotoxicity of MCPA on Tartary buckwheat and did not reduce selectivity in relation to oats.

A comparison of the costs of the recommended field treatment of a tank mix of MCPA and linuron and the experimental treatment of MCPA and added rapeseed oil was estimated (Table 29). Although the cost of MCPA with oil was higher, this treatment provided a larger percentage of weed control without a significant decrease in crop yield.

Table 28. Effect of MCPA amine (0.56 kg/ha) with added rapeseed oil on Tartary buckwheat in oats, 1974. (Means of 4 replications).

Treatments	Tartary Buckwheat: Number of plants/m^2	Tartary Buckwheat: Dry weight g/m^2	Tartary Buckwheat: Plant height cm	Oats grain yield g/m^2**
Control (weed-free)	0	-	-	357 a
Control (weedy)	146 a*	375 a	82 a	109 b
MCPA	99 b	113 b	49 b	319 a
MCPA + emulsifier	87 b	64 c	42 b	332 a
MCPA + 21.23 l/ha oil	23 c	7 d	19 c	328 a
MCPA + 0.28 kg/ha linuron	44 c	27 cd	49 b	347 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from yd^2 (0.84 m^2) extrapolated to m^2.

Table 29. Extent of control of Tartary buckwheat in oats in relation to costs of treatment with MCPA amine and rapeseed oil or with MCPA amine and linuron.

Treatment	Estimated Cost $/A*	% Weed Control (Expt. 2d)	Crop Yield (Expt. 2d) lb/A**	bu/A
Weedy control			981	28.8
MCPA amine 8 oz/A (0.56 kg/ha) + linuron 4 oz/A (0.28 kg/ha)	2.90	70	3113	91.5
MCPA amine 8 oz/A + oil (0.56 kg/ha)	4.35	84	2932	86.2

*Cost per acre times 2.471 = cost per hectare.

Costs based on the price of herbicide, oil, and emulsifier in June, 1974.

**Pounds per acre times 1.12 = kilograms per hectare.

2e. Nitrofen on Tartary buckwheat and rapeseed

2e-1. Addition of rapeseed oil to nitrofen decreased the herbicidal activity of nitrofen on Tartary buckwheat. There was a significantly greater dry weight of Tartary buckwheat in plots treated with nitrofen with added rapeseed oil than in those treated with nitrofen alone or nitrofen with emulsifier (Table 30). There were no significant differences among the nitrofen treatments on rapeseed although plots with nitrofen plus oil, yielded slightly higher than the nitrofen plots without oil.

2e-2. Addition of rapeseed oil as in 2e-1 decreased the effect of the nitrofen on Tartary buckwheat. There was, for example, a 35% increase in the number of remaining buckwheat plants compared with those after treatment with nitrofen alone (Table 31). There were no statistical differences among the nitrofen treatments on rapeseed yield, although as in 2e-1, plots with nitrofen plus rapeseed oil tended to yield slightly more than the nitrofen plots without oil. Possibly this tendency was a net effect of somewhat less crop injury outweighing influence of greater weed population. As a result of these two experiments it seems reasonable to conclude that the rapeseed oil decreases the phytotoxicity of nitrofen or in some way protects the plants from as severe an injury as results from nitrofen alone.

2f. Benazolin on cleavers and rapeseed

2f-1. The scores during the summer of 1973 indicated that there was considerable regrowth of the cleavers in the plots treated with benazolin without rapeseed oil. Addition of rapeseed oil to benazolin greatly increased the effect of the benazolin on cleavers

Table 30. Effect of nitrofen (1.12 kg/ha) with added rapeseed oil on Tartary buckwheat and rapeseed, 1973. (Means of 4 replications).

Treatments	Tartary Buckwheat: Number of plants/m^2	Tartary Buckwheat: Dry weight g/m^2	Rapeseed crop yield g/m^2**
Control	145	539 a*	211 a
Nitrofen	69	293 c	211 a
Nitrofen + emulsifier	85	307 c	204 a
Nitrofen + 11.23 l/ha oil	114	395 b	225 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from yd^2 (0.84 m^2) extrapolated to m^2.

Table 31. Effect of nitrofen (1.34 kg/ha) with added rapeseed oil on Tartary buckwheat in rapeseed, 1974. (Means of 4 replications).

Treatments	Tartary Buckwheat: Number of plants/m^2	Tartary Buckwheat: Dry weight g/m^2	Rapeseed Crop yield g/m^2**
Control (weed-free)	0	-	188 a
Control (weedy)	79 a*	223 a	86 c
Nitrofen	46 b	119 b	132 bc
Nitrofen + emulsifier	38 b	88 b	181 ab
Nitrofen + 11.23 l/ha oil	62 ab	134 ab	143 ab

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from yd^2 (0.84 m^2) extrapolated to m^2.

as shown by a 75% decrease in the dry weight of plants as compared with weights after treatment with benazolin alone. There was also a 65% decrease in dry weight of cleavers as compared with results from benazolin plus emulsifier (Table 32).

2f-2. Initial injury of the rapeseed occured with benazolin treatments in 1974. Injury was more severe with the benazolin having rapeseed oil added. The rapeseed in the benazolin treatments did recover slowly, but the stand was reduced and flowering was delayed 4 to 7 days. Ultimate recovery, however, was apparently complete, probably due to filling in by branching of the rapeseed. There was no significant difference in seed yield at harvest time. Addition of rapeseed oil increased the effect of benazolin on cleavers as shown, for example, by a 70% decrease in the dry weight of plants compared with the weight following use of 0.56 kg/ha of benazolin alone (Table 33). There was a 75% decrease in cleavers dry weight after adding oil to 0.70 kg/ha of benazolin as compared with the same rate of benazolin alone (Figs. 13, 14). The difference in the amount of cleavers alone, compared with the amount of cleavers in the rapeseed, was due to rapeseed emerging before the cleavers and the great competitive effect of the rapeseed plants themselves. This made it virtually impossible to distinguish any effect of rapeseed oil added to benazolin on the control of cleavers present in the crop.

Based on data from the cleavers growing alone in both years, it can be concluded that the addition of rapeseed oil significantly increased the phytotoxicity of benazolin on cleavers without drastically altering its selectivity with respect to the rapeseed crop.

Table 32. Effect of benazolin (0.56 kg/ha) with added rapeseed oil on cleavers, 1973. (Means of 4 replications).

Treatments	Injury Scores 0-9 scale** July 6	July 10	Aug 10	Dry weight Aug 30 g/7.3m***
Control	0	0	0	499 a*
Benazolin	3	4	2	330 b
Benazolin + emulsifier	5.5	6	4.5	228 c
Benazolin + 11.23 l/ha oil	6	7	8	79 d

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**0 = no effect, 9 = complete kill.

***Results from 4 rows 6 ft (1.83 m) long.

Table 33. Effect of different rates of benazolin with added rapeseed oil on cleavers and rapeseed, 1974. (Means of 4 replications).

Treatments	Cleavers dry weight g/9.8m** Alone	In rapeseed	Rapeseed crop yield g/m²*** With cleavers	Alone
Control (weed-free)			199 a	240 a
Control (weedy)	1136 a*	15.8	233 a	
Benazolin 0.42 kg/ha		1.3	192 a	
Benazolin + emulsifier		0.0	193 a	
Benazolin + 2.81 l/ha oil		0.0	190 a	
Benazolin + 11.23 l/ha oil		0.1	170 a	
Benazolin 0.56 kg/ha	685 b	1.5	213 a	208 a
Benazolin + emulsifier	399 c	0.1	164 a	177 a
Benazolin + 2.81 l/ha oil	259 cd	0.0	180 a	
Benazolin + 11.23 l/ha oil	204 d	0.1	183 a	150 a
Benazolin 0.70 kg/ha	605 b	4.3	210 a	210 a
Benazolin + emulsifier	310 cd	0.5	189 a	157 a
Benazolin + 2.81 l/ha oil	168 d	0.3	194 a	
Benazolin + 11.23 l/ha oil	152 d	0.3	188 a	179 a

*Means followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test (Duncan, 1955).

**Results from 4 rows 8 ft (2.44 m) long.

***Results from yd² (0.84 m²) extrapolated to m².

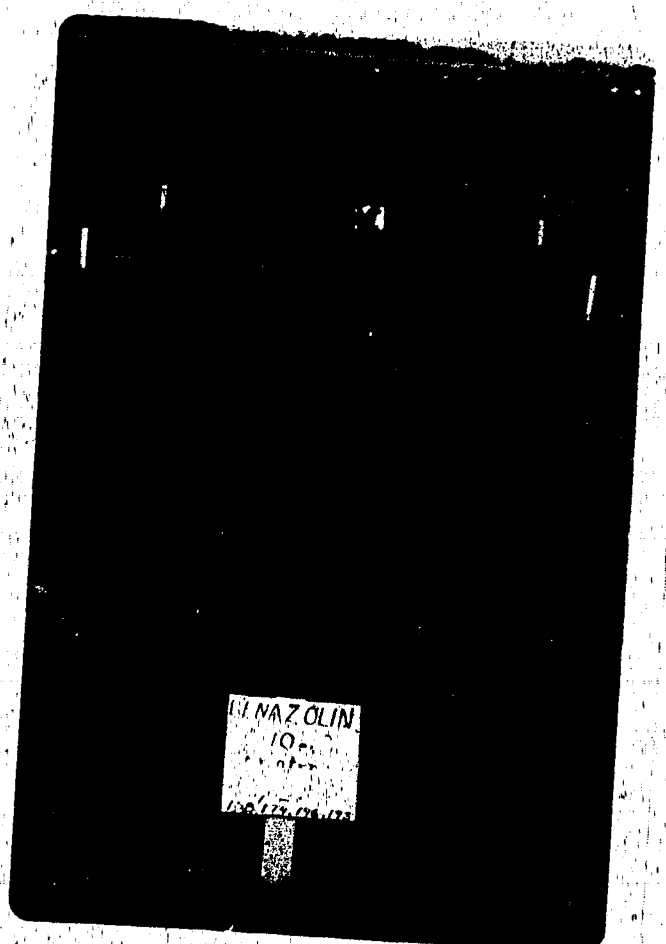

Figure 13. Cleavers grown in the field and treated at the 1-2 whorl stage with benazolin 0.70 kg/ha. Photo taken 6 weeks after spraying.

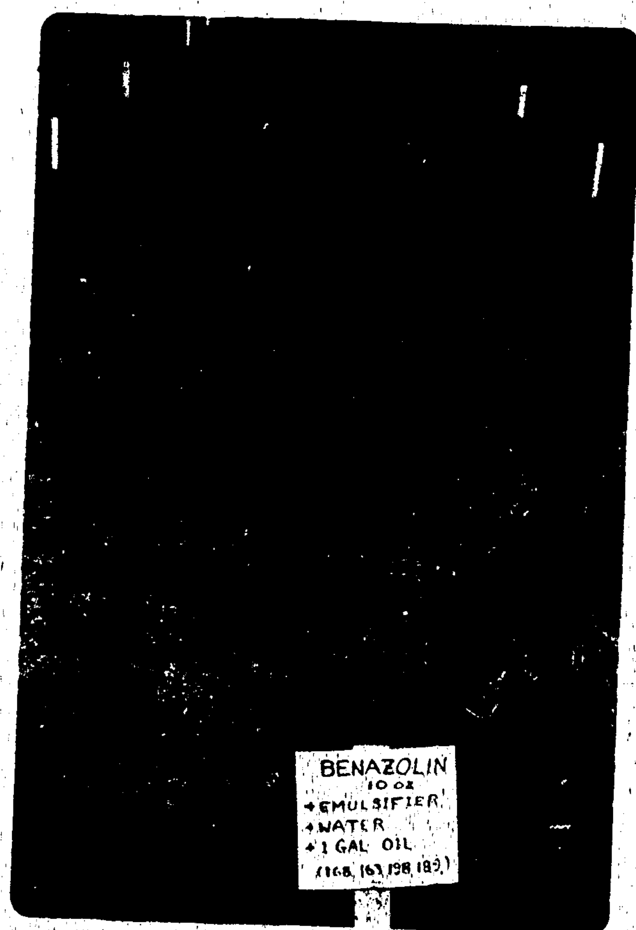

Figure 14. Cleavers treated with benazolin 0.70 kg/ha in oil-water emulsion containing 11.23 l/ha of rapeseed oil. Note the reduction in the amount of growth of cleavers compared with that in Figure 13.

Using the results from the experiment with cleavers in rapeseed, 2F-2, a comparison was made of the cost of 0.70 kg/ha (10 oz/A) of benazolin alone and the cost of 0.42 kg/ha (6 oz/A) of benazolin with 11.23 l/ha of added rapeseed oil (Table 34). The treatment of 0.42 kg/ha of benazolin with added oil was more economical and resulted in much better weed control. The crop yield was slightly less but not significantly different from the yield following 0.70 kg/ha of benazolin alone. Owing to the fact that it is impossible to screen cleavers seed from rapeseed and that 5% cleavers in rapeseed will result in the rejection of the rapeseed by crushing plants, the amount of control of this weed in the crop is an important consideration apart from any potential improvement of crop yield.

Table 34. Extent of control of cleavers in rapeseed crop in relation to costs of treatment with Benazolin with and without rapeseed oil.

Treatment	Estimated Cost $/A*	% Weed Control (Expt. 2f-2)	Crop Yield (Expt. 2f-2) lb/A**	bu/A
Weedy control	-	0	1982	39.6
Benazolin 10oz/A alone (0.70 kg/ha)	10.00	62	1684	33.7
Benazolin 6 oz/A + oil (0.42 kg/ha)	9.15	99	1524	30.5

*Cost per acre times 2.471 = cost per hectare.

Costs based on the price of herbicide, oil, and emulsifier in June, 1974.

**Pounds per acre times 1.12 = kilograms per hectare.

SUMMARY OF FIELD EXPERIMENTS

The results of the field experiments indicated that rapeseed oil did have a definite effect on certain herbicides on the weed species in the crops tested. The addition of oil significantly increased the phytotoxicity of 2,4-D amine, MCPA amine, and benazolin. There was no significant effect of added rapeseed oil on the phytotoxicity of dalapon or TCA in 1973. The results from only one year of testing indicated that the addition of oil was not as effective as the addition of emulsifier alone on the phytotoxicity of barban in 1973 and TCA in 1974. Rapeseed oil added to nitrofen tended to decrease the phytotoxicity of the nitrofen. In the instances where the oil increased the phytotoxicity of the herbicide, use of 11.23 l/ha (1.0 Imp gal/A) of rapeseed oil tended to be more effective than 2.81 l/ha (0.25 Imp gal/A) of oil.

Based on 1974 prices of herbicides and rapeseed oil, the use of rapeseed oil added to herbicides can not be recommended from a strictly economic standpoint although there was increased weed control without appreciable decrease in crop yield.

GENERAL SUMMARY

Of the 21 emulsifier products tested, Triton X-207 and Triton X-363M seemed to be the best for emulsifying rapeseed oil in water. Triton X-363M was selected for use in succeeding experiments for the following reasons. It was slightly better at low concentration for emulsifying rapeseed oil in water than was Triton X-207. Triton X-363M was less viscous and thus easier to work with than Triton X-207. In addition Triton X-207, as of May 1974, was no longer cleared by the U.S. Food and Drug administration for agricultural use. The optimum concentration range for Triton X-363M was found to be 5 to 10% v/v of the rapeseed oil. The 5% concentration was selected for use in further studies. This concentration of emulsifier did not adversely affect the growth of rapeseed plants.

The four fractions of rapeseed oil tested did not affect the growth of wild oats, rapeseed, wheat, common buckwheat, oats, barley, and faba beans. It was concluded that the crude rapeseed oil fraction, being least expensive, would be used in the succeeding studies. Results indicated that the crude rapeseed oil could be sprayed at rates as much as 112.33 l/ha (10 Imp gal/A) without damage to barley, wheat, faba beans, and rapeseed plants.

From microscopic examination of Tartary buckwheat leaves sprayed with 2,4-D amine with and without added rapeseed oil, it could be seen that the addition of oil to the spray increased wetting and spreading of the herbicide on the leaf. The cuticle layer under the oil droplets appeared to be softened or partially dissolved. It was concluded that this dissolving or softening can lead to greater penetration of the herbicide indicated by the oil induced increase in phytotoxicity of certain herbicides both in growth chamber and field experiments. The results of investigations using oil added to herbicides are summarized in the following table (Table 35). There was a significant increase in weed control without significant crop injury when rapeseed oil was added to 2,4-D amine, MCPA amine, and benazolin as compared with herbicide without added oil. It was possible to use a smaller quantity of chemical with added rapeseed oil and have weed control as good or better than from a larger rate of herbicide by itself. Consequently by the use of less herbicide the extent of the possibility for environmental contamination might be reduced.

From the economic standpoint the cost of rapeseed oil at the present time seems to limit the feasibility of its use in combination with the tested herbicides. However, rising costs of herbicides and possible increases in rapeseed production followed by surpluses and lower prices of the oil are variables which could change that conclusion.

Table 35. Summary of the effectiveness of addition of rapeseed oil to certain herbicides

Herbicide	Weed Species	Crop Species	Number of Experiments (G = Growth Chamber, F = Field): Total	Number of Experiments (G = Growth Chamber, F = Field): Statistically Significant Improvement by oil	Page [illegible] Reference	Comments
2,4-D amine	Tartary buckwheat	Wheat Barley	[illegible]	[illegible]	[illegible]	Improved weed control. No crop injury. Additional 2 growth chamber experiments showed trends toward improvement by oil.
Barban	Wild oats	Wheat Rapeseed	[illegible]	[illegible]	[illegible]	There were trends toward improvement by oil in the other growth chamber experiments but no effect in the field. No crop injury.
Dalapon	Green foxtail	Barley Rapeseed	[illegible]	[illegible]	[illegible]	There were trends toward improvement by oil in the other growth chamber experiments but no effect in the field. No rapeseed injury. Barley injured more with oil added to herbicide.
TCA	Green foxtail	Barley Rapeseed Oats	[illegible]	[illegible]	[illegible]	There were trends toward improvement by oil in other growth chamber experiments but no effect in the field. No crop injury.
MCPA amine	Tartary buckwheat Hempnettle	Oats Wheat	[illegible]	[illegible]	[illegible]	Improved weed control. No crop injury. Additional 2 growth chamber experiments showed trends toward improvement by oil.
Chloroxuron	Green foxtail	Faba beans	[illegible]	[illegible]	[illegible]	Faba beans injured more with oil added to herbicide.
Nitrofen	Tartary buckwheat	Rapeseed	[illegible]	[illegible]	[illegible]	Oil [illegible] effect on Tartary buckwheat. No crop injury.
Benazolin	Cleavers	Rapeseed	[illegible]	[illegible]	[illegible]	Improved weed control. No crop injury. One additional growth chamber experiment showed trend toward improvement by oil.

LITERATURE CITED

Addink, S. and J.D. Nalewaja. 1972. Effects of additives on dicamba. Proc. N. Cent. Weed Control Conf. 27: 47-48.

Almodovar-Vega, L. and R.D. Ilnicki. 1972. Enhancing atrazine activity with additions of mineral and vegetable oils. Weed Abstr. 21 (2): 87.

Anderson, G.W. 1963. Post-emergence application of atrazine in oil/water emulsions. Res. Rep. National Weed Comm. E. Sec., 21-22.

Anderson, G.W. and G.E. Jones. 1964a. Twitchgrass control in corn. Res. Rep. National Weed Comm. E. Sec., 16.

Anderson, G.W. and G.E. Jones. 1964b. Weed control with single and multiple applications of atrazine in an oil/water emulsion. Res. Rep. National Weed Comm. E. Sec., 17.

Anderson, G.W. and G.E. Jones. 1964c. Farm tests of atrazine applied as a foliar spray in water and in an oil/water emulsion. Res. Rep. National Weed Comm. E. Sec., 18-19.

Anderson, R.N. 1968. Effects of post-emergence chloroxuron treatments on weed-free soybeans. Proc. N. Cent. Weed Control Conf. 23: 27.

Anderson, R.N. and D.L. Ziebart. 1969. Evaluation of herbicides in a soybean weed nursery. Res. Rep. N. Cent. Weed Control Conf., 152-155.

Ashton, F.M. and A.S. Crafts. 1973. Phenols. *In* Mode of Action of Herbicides. Wiley-Interscience Publ., 256-259.

Aya, F.O. and S.K. Ries. 1968. Influence of oils on the toxicity of amitrol to quackgrass. Weed Sci. 16: 288-290.

Bandeen, J.D. 1969. Wetting agents, oils: are they a plus for atrazine? Crops and Soils 21: 15.

Barrentine, J.L. and G.F. Warren. 1970. Isoparaffinic oil as a carrier for chlorpropham and terbacil. Weed Sci. 18: 365-372.

Bio-Veg. 1971. Technical bulletin. Rancher Products, Minneapolis, Minn.

Brown, R.H. and R. Frank. 1966. Directed herbicides X additives in field corn. Res. Rep. National Weed Comm. E. Sec., 34-35.

Burr, R.J. and G.F. Warren. 1971. Selectivity of dinoseb in an isoparaffinic oil carrier. Weed Sci. 19: 706-708.

Caseley, J.C. 1970. Improved weed control techniques employing lower doses can reduce herbicide residues. Proc. 10th Br. Weed Control Conf. 3: 1071-1078.

Coats, G.E. and C.L. Foy. 1971. Four vegetable oils as atrazine and 2,4-D penetrant aids for the species of their origin. Abstr. Weed Sci. Soc. Amer., 22.

Coats, G.E. and C.L. Foy. 1974a. Effect of atrazine-phytobland oil combinations on $^{14}CO_2$-fixation and transpiration. Weed Sci. 22: 215-220.

Coats, G.E. and C.L. Foy. 1974b. Effect of petroleum oils on the uptake of atrazine-^{14}C by corn. Weed Sci. 22: 220-226.

Crafts, A.S. and C.L. Foy. 1962. The chemical and physical nature of plant surfaces in relation to the use of pesticides and to their residues. Residue Reviews 1: 112-139.

Crafts, A.S. and H.G. Reiber. 1952. Herbicide uses of oils. Agricultural application of petroleum products. Advances in Chemistry Series. (Am. Chem. Soc. Publ.) 7: 70-75.

Degroot, G., E. Ratledge, C. Vachette, P. Faillet, R. Sohet, and J. Schnaphauf. 1970. Possibilities of increasing the effectiveness of post-emergence herbicides used in sugar beets by highly refined non-phytotoxic paraffinic oil. Proc. 10th Br. Weed Control Conf. 2: 605-609.

Dexter, A.G. 1972. Postemergence herbicides plus additives applied to sugar beets untreated and pretreated with EPTC. Res. Rep. N. Cent. Weed Control Conf., 136-137.

Dexter, A. and G.H. Smith. 1969. The influence of spray additives on post-emergence weed control in sugar beets. Proc. N. Cent. Weed Control Conf. 24: 31-32.

Downey, R.K. 1965. Rapeseed botany, production, and utilization. *In* Rapeseed Meal for Livestock and Poultry - A Review. Canada Department of Agriculture Publication 1257: 7-23.

Downey, R.K., A.J. Klassen, and J. McAnsh. 1974. Rapeseed: Canada's "Cinderella" Crop. Rapeseed Association of Canada Publication No. 33.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Ennis, W.B. Jr. 1951. Influence of different carriers upon the inhibitory properties of growth-regulatory sprays. Weeds 1: 43-47.

Foden, P.C. 1972. Factors affecting efficacy of foliage-applied herbicides application factors. Proc. 11th Br. Weed Control Conf. 3: 1129-1140.

Foy, C.L. 1964. Review of herbicide penetration through plant surfaces. J. Agr. Food Chem. 12: 473-476.

Gertsch, M.E. 1952. The influence of various carriers upon the inhibitory effectiveness of 2,4-D sprays. Weeds 2: 33-42.

Gossett, B.J. and C.E. Rieck. 1971. Performance of chloroxuron as influenced by spray additives, spray volume, and early morning versus late afternoon applications. Weed Abstr. 20(6): 446-447.

Hammond, J.W. 1967. Those Durable Oils. Part C - Herbicidal oils. Farm Chemicals and Crop Life, 130: 36,38,40.

Havis, R., S. Dallyn, and R.D. Sweet. 1952. Herbicidal properties of petroleum hydrocarbons. Agricultural application of petroleum products. Advances in Chemistry Series (Am. Chem. Soc. Publ.) 7: 76-83.

Hogue, C.W. 1974. Response of cotton and weeds to herbicides with phytobland oil or surfactant. Weed Sci. 22: 97-101.

Jansen, L.L. 1964. Surfactant enhancement of herbicide entry. Weeds. 12: 251-255.

McGlamery, M.D. 1971. The use of oils in post-emergence weed sprays. Weeds Today 2(1): 13.

McGlamery, M.D. and F.W. Slife. 1973. Post-emergence herbicides on corn at Urbana, Illinois. Res. Rep. N. Cent. Weed Control Conf., 160.

Messersmith, C.G. 1973. Comparison of single and split application of bentazon for Canada thistle control. Res. Rep. N. Cent. Weed Control Conf., 31.

Miller, G. 1967. Performance of atrazine-oil in Minnesota. Proc. N. Cent. Weed Control Conf. 22: 57-58.

Miller, S. and J.D. Nalewaja. 1970. Oil additives to phenmedipham for weed control in sugar beets. Proc. N. Cent. Weed Control Conf. 25: 64-66.

Miller, S.D. and J.D. Nalewaja. 1973. Effect of additives upon phenmedipham for weed control in sugar beets. Weed Sci. 21: 67-70.

Mitich, L.W. 1972. Chemical weed control in corn. Res. Rep. N. Cent. Weed Control Conf., 143.

Nalewaja, J.D. 1968. Post-emergence atrazine treatments for weed control in corn. Proc. N. Cent. Weed Control Conf. 23: 12-13.

Nalewaja, J.D. 1972a. Cyanazine plus oil post-emergence. Res. Rep. N. Cent. Weed Control Conf., 141.

Nalewaja, J.D. 1972b. Bentazon plus oil additives. Res. Rep. N. Cent. Weed Control Conf., 204.

Nalewaja, J.D. 1972c. Barban plus nitrogen or MCPA for wild oats control. Res. Rep. N. Cent. Weed Control Conf., 82.

Nalewaja, J.D. 1974. Will vegetable oils replace petroleum as adjuvants to herbicides? Weeds Today 5(3): 17-18.

Nalewaja, J.D., K. Adamczewski, and M. Krol. 1974a. Cyanazine plus oil additives. Res. Rep. N. Cent. Weed Control Conf., 191.

Nalewaja, J.D., K. Adamczewski, and M. Krol. 1974b. Oil additives to bentazon. Res. Rep. N. Cent. Weed Control. Conf., 124.

Nalewaja, J.D. and C. Messersmith. 1968. Herbicide evaluation for weed control in sugar beets. Res. Rep. N. Cent. Weed Control Conf., 67.

Nalewaja, J.D., J. Pudelko, and B. Skoplec. 1973. Influence of oil additives on foxtail control with cyanazine. Proc. N. Cent. Weed Control Conf. 28: 79.

Parr, J.F. and A.C. Norman. 1965. Considerations in the use of surfactants in plant systems: a review. Botan. Gaz. 126(2): 86-96.

Peacock, J.F. 1970. Enhancement of foliar penetration and herbicide activity by oils. Dissert. Abstr. Intern. 31: 4431-B-32-B.

Peacock, J.F. and C.D. Dybing. 1969. Properties of crop oils as related to enhancement of herbicide activity. Proc. N. Cent. Weed Control Conf. 24: 80-81.

Peterson, G.E. 1967. The discovery and development of 2,4-D. Agricultural History 41: 243-253.

Robertson, M.M. and R.C. Kirkwood. 1969. The mode of action of foliage-applied translocated herbicides with particular reference to the phenoxy-acid compounds. I. The mechanisms and factors influencing herbicide absorption. Weed Res. 9: 224-240.

Robinson, E.L. 1973. Weed control in cotton with emulsified oils and herbicidal naphtha. Weed Sci. 21: 402-404.

Ross, M.A. and J.L. Williams, Jr. 1967. Early post-emergence herbicide performance in corn. Proc. N. Cent. Weed Control Conf. 22: 60.

Saunders, R.K. and W.M. Lonnecker. 1967. Physiological aspects of using non-phytotoxic oils with herbicides. Proc. N. Cent. Weed Control Conf. 22: 62-63.

Schrader, J.W. 1970. Influence of oil and environmental factors on phytotoxicity and foliar penetration of atrazine. Dissert. Abstr. Intern. 31: 2422-B-23-B.

Smith, R.J. Jr. 1974. Propanil and adjuvants for barnyardgrass control in rice. Weed Sci. 22: 419-422.

Stahlman, P.W. and C.G. Messersmith. 1973. Effects of additives on 2,4-D. Proc. N. Cent. Weed Control Conf. 28: 98.

Van Overbeek, J. and R. Blondeau. 1954. Mode of action of phytotoxic oils. Weeds. 3: 55-65.

Verstraete, W.C. and J.D. Bandeen. 1966. Effect of spraying atrazine oil-water emulsions on foxtail at different stages of growth. Res. Rep. National Weed Comm. E. Sec., 32-33.

Warrington, N. and Wm. G. Corns. 1973. Enhancement of the effect of 2,4-D amine on Tartary buckwheat by the inclusion of rapeseed oil in the spray. Res. Rep. Canada Weed Comm. W. Sec., 274-275.

Warrington, N. and Wm. G. Corns. 1974. Enhancement by rapeseed oil of the activity of 2,4-D amine on Tartary buckwheat in wheat. Res. Rep. Canada Weed Comm. W. Sec., 18-19.

Western Canadian Seed Processors Ltd. Lethbridge, Alberta. 1973. Technical data sheet.

Wicks, G.A., O.C. Burnside, and C.R. Fenster. 1967. Progress report on weed control in sorghum with atrazine plus oil in Nebraska. Proc. N. Cent. Weed Control Conf. 22: 58-59.

Wicks, G.A., O.C. Burnside, and C.R. Fenster. 1968. Effect of atrazine and oil on weed control in sorghum across Nebraska in 1968. Proc. N. Cent. Weed Control Conf. 23: 14.